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SOIL ACIDITY AS AFFECTED BY MOISTURE CONDITIONS OF THE SOIL

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INTRODUCTION

In an investigation of soils from tiled and untiled land it has been found that the drained was not as acid as the undrained soil (*2*).[1] To throw more light on the effect of moisture on soil acidity, five typical acid Indiana soils were selected for investigation under controlled moisture conditions: Soil A, a yellow silty clay from Jennings County; soil B, a whitish silt loam from Jennings County; soil C, a brown silt loam from Tippecanoe County; soil D, a black peaty sand from La Porte County; and soil E, a dark-brown peat from De Kalb County.

Equal quantities of each of these soils, the analyses of which are given in Table I, were kept in pots in the greenhouse at full water-holding capacity, at one-half water-holding capacity, and at one-fourth water-holding capacity. Other portions of each soil were taken when pots were filled and kept in an air-dry condition in the laboratory. The pots were of galvanized iron of 770 cubic inches capacity, heavily coated on the inside with paraffin. The soil in each pot was kept under the desired moisture conditions by weighing them two or three times each week and replenishing the evaporated moisture with pure distilled water. The water-holding capacity of each soil was determined by placing a perforated bottom cylinder containing about 100 gms. of loose dry soil in a vessel of water and allowing the sample to become thoroughly saturated, then weighing. The soils fully saturated with water soon became more or less puddled, and the moisture determinations of these samples taken at the end of the test showed less than the calculated percentage of water. The moisture determinations of the samples with one-fourth and one-half water-holding capacity were approximately the same as the calculated percentages. The soils were placed in the pots February 27, 1917, and the experiment was continued for one year, after which they were sampled by means of a soil tube, taking a vertical core of soil to the full depth of the pot. Each sample was thoroughly mixed and divided

[1] Reference is made by number (italic) to "Literature cited," p. 329.

into two portions, one of which was sealed in an air-tight jar. The other was spread out and air-dried in the laboratory. Moisture was determined in both the moist and the air-dry samples. Acidity was determined by the Hopkins potassium-nitrate method,[1] by the C. H. Jones calcium-acetate method (*4*), and by the ethyl-acetate method (*1*). The results of these determinations are given in Table II. In making the acidity determinations, the moisture contents of the soils were taken into consideration so that the proportions of dry soil to water and reagent used in making the tests were the same for all samples of both wet and air-dry soils.

TABLE I.—*Analyses of soils used*

Determined.[a]	A.	B.	C.	D.	E.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Volatile matter	3.57	3.92	7.45	10.13	85.20
Potassium oxid (K_2O)	.27	.25	.40	.21	.17
Calcium oxid (CaO)	.18	.17	.37	.10	.46
Magnesium oxid (MgO)	.40	.24	.61	.23	.20
Manganese oxid (Mn_3O_4)	.08	.04	.17	.04	.02
Ferric oxid (Fe_2O_3)	3.68	1.28	3.04	1.04	.48
Aluminium oxid (Al_2O_3)	4.68	2.80	4.57	3.09	.85
Phosphorus oxid (P_2O_5)	.05	.06	.15	.10	.13
Sulphate (SO_3)	.12	.10	.16	.11	.31
Residue	87.76	92.57	83.42	85.50	12.31
Nitrogen	.07	.12	.22	.40	2.04
Humus (acid) [b]	.73	1.31	2.25	5.72	50.19
Humus [c]	.70	1.17	3.13	4.96	52.00
Hygroscopic moisture	1.50	1.30	1.84	1.90	8.38
Acidity:					
Potassium-nitrate method [d] lb.	5,460	2,220	460	2,520	5,080
Calcium-acetate method [d] lb.	5,875	4,875	8,125	10,625	69,750
Water-holding capacity [e]	48.6	48.7	55.1	67.1	200.0

[a] WILEY, H. W., ed. OFFICIAL AND PROVISIONAL METHODS OF ANALYSIS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), 272 p., 13 fig. 1908. Reprinted, 1912.

[b] Ammonia soluble without previous washing with dilute hydrochloric acid.

[c] Washed with hydrochloric acid, digested with ammonia, filtered, and refiltered till clear.

[d] Pounds of calcium carbonate required to neutralize 2,000,000 pounds of soil.

[e] Water-holding capacity in grams of water per 100 gm. of dry soil.

In studying the results given in Table II, the following rather striking points are noted:

In each soil the degree of acidity, as indicated by all the methods used, was greater when the soil was held at one-half water-holding capacity than when it was held at one-fourth water-holding capacity.

All the soils which had been carried at one-half water-holding capacity were more acid than they were at the beginning of the experiment. This is in accord with the results obtained by Noyes and Yoder (*5*).

The soils high in organic matter gave greater acidity when held at full water capacity than when kept one-half saturated with water. The soils low in organic matter gave a lower degree of acidity when kept at full water than when kept at one-half water-holding capacity.

[1] WILEY, H. W., ed. op. cit.

TABLE II.—*Relative acidities of soils with different moisture conditions, and changes due to drying*

Soil.	Moisture treatment.	Potassium-nitrate method.[a]			Calcium-acetate method.[a]			Ethyl-acetate method.[b]		
		Moist.	Dried.	Change.	Moist.	Dried.	Change.	Moist.	Dried.	Change.
A[c]...	Start		5,460			5,875				
	End		4,160			7,000				
	¼ water	6,165	6,150	− 15	9,500	9,000	− 500	0.0011	0.0006	−0.0005
	Full water	3,750	3,475	− 275	7,000	6,250	− 750	.0009	.0006	− .0003
B....	Start		2,220			4,875				
	End		1,720			5,000				
	¼ water	3,075	3,100	+ 25	6,250	6,250	0	.0034	.0011	− .0023
	½ water	3,625	3,725	+ 100	7,500	7,000	− 500	.0038	.0017	− .0021
	Full water	2,200	1,775	− 425	6,500	5,500	−2,000	.0026	.0013	− .0013
C....	Start		460			8,125				
	End		360			7,500				
	¼ water	725	650	− 75	8,000	9,000	+1,000	.0027	.0013	− .0014
	½ water	1,000	975	− 25	8,750	10,000	+1,250	.0029	.0013	− .0016
	Full water	2,150	450	−1,700	6,250	5,000	−1,250	.0025	.0011	− .0014
D....	Start		2,520			10,625				
	End		2,360			9,500				
	¼ water	2,875	3,125	+ 250	10,750	13,000	+2,250	.0081	.0050	− .0031
	½ water	3,300	3,625	+ 325	11,500	12,500	+1,000	.0090	.0050	− .0040
	Full water	3,700	1,850	−1,850	12,000	9,500	−2,500	.0090	.0055	− .0035
E....	Start		5,080			69,750				
	End		5,000			66,000				
	¼ water	3,950	4,000	+ 50	63,500	63,500	0	.0082	.0064	− .0017
	½ water	5,675	5,400	− 275	72,500	65,000	−7,500	.0103	.0064	− .0039
	Full water	8,000	6,720	−1,280	76,000	69,500	−6,500	.0120	.0060	− .0060

[a] Results expressed in pounds of calcium carbonate required for 2,000,000 pounds soil.

[b] Ten gm. of soil were placed in 100 cc. of pure 5 per cent ethyl-acetate solution and shaken at frequent intervals. The solutions were kept in a thermostat at 25° C. for 24 hours. Then 10 cc. of the supernatant liquid was removed and titrated with $N/20$ sodium hydroxid, phenolphthalein being used as the indicator. The figures reported are the constants calculated from the formula $K=\frac{1}{t}(\log a/a-x)$, where a equals grams of ethyl acetate at start and $a-x$ equals grams of ethyl acetate left at t (one day). The constant for $N/1{,}000$ acetic acid carried under like conditions was 0.0004 and for $N/1{,}000$ nitric acid it was 0.0030. These constants are relative only. Autocatalysis was noted in longer time reactions, but this factor has been ignored in the calculations reported.

[c] There was not enough of soil A, and the one-fourth water-holding capacity pot was omitted.

When the samples of moist soil taken at the close of the experiment were air-dried, those samples that had been kept saturated decreased markedly in acidity according to all methods used. When the samples kept at one-fourth and one-half water capacities were air-dried, all deceased in acidity according to the ethyl-acetate method, but the Hopkins and Jones methods gave both increases and decreases in acidity. While the acidity was generally decreased when the soils were air-dried, the degree of acidity equilibrium reached varied to a large extent, owing to the condition of equilibrium caused by the variation in moisture content at which the soil had been held. For instance, while undried soils containing much organic matter gave a higher acidity at full water than at half water capacity, these same soils when air-dried gave a much lower acidity after being held at full water than when held at one-half water-holding capacities. This reversal in order of acidity is not so apparent with soils low in organic matter.

Preliminary tests were made on the soils from samples taken nine months from the beginning. The results obtained with the samples from the pots of fully saturated soil show the extreme sensitiveness of

soils to slight variations in moisture. The sample of fully saturated soil C, taken at nine months, lost some moisture before it was determined, in which condition it had 27.2 per cent of water and 400 pounds' acidity by the potassium-nitrate method. Three months later a sample of soil from the same pot had an acidity by the same method of 2,150 pounds with 30.6 per cent of water. The soil from this pot showed but a slight trace of iron in the potassium-nitrate extract with 27.2 per cent of water and a very large amount with 30.6 per cent of water. This increase in acidity and of soluble iron appears to be due to the fully satuated condition rather than the longer time elapsed.

The relative acidities of the various soils, high or low in organic matter, gave quite wide variations with the different methods. In general, the potassium-nitrate method measures mineral acidity, owing to acid-reacting silicates, and to a less degree it measures acid organic matter in the soil. The calcium-acetate method, on the other hand, measures acidity due to acid-reacting silicates, and in addition it responds readily to acid organic matter. With soils high in organic matter the results due to this method are influenced by organic matter more than by acid silicates. Water-soluble acidity only slightly affects the results shown by either the potassium-nitrate or the calcium-acetate methods. The results shown by the ethyl-acetate test are very largely in proportion to the strength of the water-soluble acidity of the soil. These results would be affected by nitrates, sulphates, or chlorids of aluminium, iron, and to a slight degree by manganese salts; also by any soluble acid reacting organic matter. Pure silicates which show a very high acidity by other methods and which are not soluble in water do not affect ethyl acetate at all (1).

In titrating the potassium-nitrate acidity determinations, quite distinct differences were noted in the character of the precipitates formed. In order to study this point, determinations were made of the metals which had been dissolved in the reactions between the normal potassium-nitrate solution and the soil. Table III gives the bases and soluble silica found in 100 cc. of potassium-nitrate extract from both the wet and the air-dried soils; also the increases or decreases of soluble matter found on air drying the soil samples. These results show that considerable iron was made soluble when the soil was kept fully saturated. This soluble iron was apparently all in the ferrous state. After the soils were air-dry, the iron was very quickly and almost completely oxidized, as the air-dry soil showed but little soluble iron. This chemical change in the condition of the iron undoubtedly accounts for a large part of the decrease in acidity caused by drying the fully saturated samples. Soluble iron is seldom found in soil solutions in very large amounts, which is undoubtedly due to the fact that the usual procedure in preparing soil samples for analysis is first to air-dry them, allowing ample opportunity for the oxidation of the iron.

TABLE III.—*Soluble oxids in normal potassium-nitrate extract of soils with changes due to drying*

[Results expressed as grams of oxids per 100 cc. of extract from acidity determinations]

Soil.	Moisture treatment.	Silicic oxid.			Aluminium oxid.			Ferric oxid.		
		Wet.	Dry.	Change.	Wet.	Dry.	Change.	Wet.	Dry.	Change.
A	⅛ water	0.0062	0.0065	+0.0003	0.0421	0.0382	−0.0039	0.0020	0.0010	−0.0010
	Full water	.0045	.0048	+ .0003	.0179	.0180	+ .0001	.0040	.0020	− .0020
B	⅛ water	.0049	.0039	− .0010	.0207	.0250	+ .0043	.0030	.0020	− .0010
	½ water	.0045	.0057	+ .0012	.0210	.0236	+ .0026	.0030	.0020	− .0010
	Full water	.0046	.0024	− .0022	.0079	.0078	− .0001	.0140	.0030	− .0110
C	⅛ water	.0032	.0036	+ .0004	.0075	.0070	− .0005	.0020	.0010	− .0010
	½ water	.0037	.0066	+ .0029	.0084	.0056	− .0028	.0020	.0010	− .0010
	Full water	.0034	.0032	− .0002	.0072	.0054	− .0018	.0240	.0010	− .0230
D	⅛ water	.0050	.0054	+ .0004	.0193	.0258	+ .0065	.0030	.0010	− .0010
	½ water	.0056	.0041	− .0015	.0234	.0304	+ .0070	.0020	.0010	− .0010
	Full water	.0049	.0030	− .0019	.0225	.0068	− .0157	.0180	.0040	− .0140
	⅛ water	.0053	.0021	− .0032	.0210	.0136	− .0074	.0020	.0020	.0000
	½ water	.0058	.0030	− .0028	.0199	.0166	− .0033	.0020	.0020	.0000
	Full water	.0090	.0040	− .0050	.0207	.0138	− .0069	.0380	.0040	− .0340

Soil.	Moisture treatment.	Manganese oxid.			Calcium oxid.			Magnesium oxid.		
		Wet.	Dry.	Change.	Wet.	Dry.	Change.	Wet.	Dry.	Change.
A	⅛ water	0.0086	0.0064	−0.0022	0.0370	0.0408	+0.0038	0.0126	0.0124	+0.0008
	Full water	.0200	.0200	.0000	.0288	.0488	+ .0200	.0141	.0135	− .0006
B	⅛ water	.0035	.0035	.0000	.0350	.0380	+ .0030	.0070	.0069	− .0001
	½ water	.0034	.0030	− .0004	.0316	.0336	+ .0020	.0065	.0056	− .0009
	Full water	.0069	.0078	+ .0009	.0387	.0448	+ .0061	.0087	.0066	− .0021
C	⅛ water	.0080	.0080	.0000	.1223	.1298	+ .0175	.0105	.0133	+ .0028
	½ water	.0040	.0060	+ .0020	.1251	.1302	+ .0051	.0130	.0136	+ .0006
	Full water	.0324	.0356	+ .0032	.0814	.1264	+ .0450	.0134	.0152	+ .0018
D	⅛ water	.0040	.0040	.0000	.0122	.0128	+ .0006	.0042	.0041	− .0001
	½ water	.0020	.0020	.0000	.0066	.0094	+ .0028	.0021	.0028	+ .0007
	Full water	.0040	.0040	.0000	.0143	.0212	+ .0069	.0051	.0041	− .0010
	⅛ water	.0052	.0034	− .0018	.0626	.0612	− .0014	.0086	.0054	− .0032
	½ water	.0056	.0034	− .0022	.0541	.0376	− .0165	.0072	.0046	− .0026
	Full water	.0034	.0036	+ .0002	.0504	.0464	− .0040	.0086	.0055	− .0031

There was a great difference in the amounts of manganese found in some of the soils. The manganese, like the iron, appears to have been very largely reduced and made soluble by saturating the soil with water and excluding the air. In soils A and C over one-half the total soil manganese was dissolved by the potassium-nitrate solution. Unlike iron, the manganese did not rapidly oxidize upon air-drying the soil. Undoubtedly, under proper conditions, oxidation of manganese takes place, although much less rapidly than that of iron. In view of the wide variations between the manganese results, new solutions were prepared, and the gravimetric determinations were checked and confirmed by means of the Volhard volumetric and the lead-peroxid colorimetric methods.

The soluble aluminium decreased when the fully saturated soils containing much organic matter were dried. With soils B and D, one-fourth and one-half saturated with water, the soluble aluminium increased on air-drying. This is in accord with the acidity, which likewise increased when these soils were dried. Different investigators have endeavored to correlate the amounts of soluble aluminium and iron with the degree of acidity as obtained with the potassium-nitrate method. The results given in Tables II and III show a certain correlation along this line, but it is very apparent that the titrated acidity can not be entirely explained on the basis of the amount of potassium-nitrate soluble aluminium and iron. This acidity is apparently partly due to soluble acid organic compounds in addition to the iron and aluminium compounds.

The amount of calcium in solution varied to a large degree in inverse relation to the aluminium and iron. In all the soils, except the peat (E), the solutions from the air-dried soils contained more calcium than did those from the undried soils. Magnesium and soluble silica showed no striking variations due to the varied moisture conditions.

The changes shown in the degrees of acidity and also the differences in the amounts of soluble bases occurring when the soil samples are air-dried indicate the importance of further study of soils and soil reactions on samples which are kept under field moisture conditions. Some of the reactions which occur when soils are dried are apparently very rapid and so slowly reversible that the composition of dried soils may be quite different from that of field soils.

MOISTURE REACTIONS OF ACID SOILS

It has been noted by different investigators that carbonated water will extract from a mineral soil a solution that on boiling to drive off the carbon dioxid will be alkaline to phenolphalein. This fact can hardly be taken as proof that the soil moisture is not acid or that the soil acidity has been regulated by the formation of carbonates. Such an extraction of bases by an acid is, of course, to be expected from the laws of chemistry, but it does not tell in what state of equilibrium the soil bases may have been before they were extracted. Recent researches would indicate that the soil moisture of acid soils is distinctly acid and not basic in reaction. Gillespie (*3*), working with the hydrogen electrode, has found that solutions of acid soils are distinctly acid in reaction. Sharp and Hoagland (*6*) likewise found that there is an excess of hydrogen ions in solutions of acid soils. In addition they say:

> Soils containing calcium in equilibrium with HCO_3 and CO_2 have a very slightly alkaline reaction

and

> The figure for Ca $(HCO_3)_2$ is almost identical with those obtained for the alkaline soils.

Truog (7) and Meacham found that the reaction of the plant sap of a number of agricultural plants was always acid. As most plants will grow in slightly acid soils and in slightly acid water cultures, it does not seem necessary nor even possible that in such cases calcium is first transformed into bicarbonate before it is assimilated. As a result of varying the moisture conditions of acid soils it is very evident from the results given in Tables II and III that chemical reactions take place as different conditions of equilibrium due to moisture and aeration are established. These reactions are in the nature of reduction, oxidation, and hydrolysis as well as interactions following the law of mass action between compounds which may be made chemically active. All of these chemical changes in the soil cause variations in the degree of water-soluble acidity, as shown by the ethyl-acetate reaction as well as of the less-soluble acidity which is shown by the soluble-salt methods. These changes would no doubt also affect the toxicity of acids and other compounds in the soil. For instance, it may be readily seen that the oxidation of iron in the soil from the ferrous to the ferric condition would reduce toxicity as well as acidity. Acid marsh soils containing much iron are unproductive until some time after they have been drained. These soils when properly drained become quite red from oxidized iron, in which condition they are much more productive. This fact is a matter of common knowledge among observant farmers in such regions. It is undoubtedly true that soil processes in which carbon dioxid is evolved also produce material changes in soil acidity (5). Nitrification also increases water-solubility acidity. These biological reactions, of course, depend materially upon soil-moisture conditions.

FACTORS AFFECTING SOIL ACIDITY

Primarily soil acidity is due to an excess of acid-reacting compounds, or, in other words, to a deficiency of bases. This deficiency of bases is caused to a large extent by the leaching of the calcium and magnesium in the drainage waters. A lesser factor is the removal of mineral bases by crops. Under ordinary conditions of decay the carbonaceous and nitrogenous matter of plants takes on an acid character, tending to neutralize bases in the soil. The acidity of peat soils is very largely organic, as shown by the fact that the ash of the most acid peat is basic in reaction. In mineral soils there is an enormous excess of silicic oxid. This silicic oxid when free is insoluble and inactive as an acid; but it is potentially acid, and under humid conditions tends to form chemically-active acid-reacting silicates of iron, aluminium, and manganese. The degree of acidity of aluminium silicate is in proportion to the ratio of silicic oxid and aluminium oxid and also to the amount of combined water the silicate contains (1). Everything else being equal, the more water there is in the silicate, the more active it is chemically and the more acid it is in reaction. The measurable acidity of the organic matter

of soils is also increased in the presence of an excess of water, as indicated from the results obtained with soil E. Drainage conditions will modify the acidity of either an organic or inorganic soil, and this will have an effect on soil fertility. Of course with soils well supplied with calcium and magnesium, poorly-drained soils would not become acid until a part of the bases were dissolved and washed away.

SUMMARY

(1) Five different types of acid soils were kept under different moisture conditions in pots in the greenhouse for one year. Portions of soil were kept one-fourth saturated, one-half saturated, and fully saturated; also in an air-dry condition.

(2) Acidity determinations were made by the Hopkins potassium-nitrate method, the C. H. Jones calcium-acetate method, and the ethyl-acetate method. Samples of soil from each pot were tested for acidity both in the moist and in the air-dried condition. The potassium-nitrate extracts were analyzed.

(3) The degree of soil acidity measured by the different methods varied with different moisture conditions.

(4) With each soil and each method used the samples which had been kept half-saturated were higher in acidity than they were at the start of the experiment. The acidity of the half-saturated soils was greater than the acidity of the fourth-saturated soils.

(5) The soils high in organic matter showed the greatest acidity when kept fully saturated. The soils low in organic matter showed the greatest acidity when kept half-saturated.

(6). When the moist samples of soil taken at the close of the experiment were air-dried, the fully-saturated samples showed loss of acidity. The half- and fourth-saturated samples showed both gains and losses in acidity when air-dried.

(7) The potassium-nitrate extracts of the fully-saturated soils contained much larger amounts of iron than extracts of other samples. This soluble iron was in the ferrous form and was oxidized and made insoluble when the soils were dried.

(8) With the mineral soils the fully saturated soils had much greater amounts of soluble manganese than the other samples. Drying the soils did not render the manganese insoluble as it did the iron.

(9) There was less soluble aluminium in the fully saturated mineral soils, but with the soils high in organic matter this was not true. There was both increase and decrease of soluble aluminium on drying the soils.

(10) Calcium, magnesium, and silica showed variations in solubility owing to different moisture conditions, but the variations were not as striking as those of iron, manganese, and aluminium.

(11) In correlating the soluble iron and aluminium with the acidity obtained from the potassium-nitrate extracts, it was apparent that the titrated acidity could not be entirely explained on this basis. Doubtless this acidity is partly due to soluble acid organic compounds.

(12) The measurable acidity of acid soils varies to a large degree under different conditions of moisture and aeration. These variations are due to chemical rather than physical changes in the soils.

(13) The extreme sensitiveness of the chemical compounds of soils and the wide variations caused by changing moisture conditions leads to the conclusion that some soil investigations should be conducted with undried samples.

(14) The soil moisture of acid soils is acid in reaction as shown by hydrogen-ion determinations. As the cell sap is also acid it is not necessary to consider that calcium is first changed into the form of bicarbonate before it can aid in nitrification or be assimilated by plants.

(15) A condition of acidity is produced in humid soils due to the leaching of the strong basic elements in the drainage water, by the removal of bases in crops, by the decay of carbonaceous and nitrogenous substances, and by the hydrolysis of mineral compounds and organic matter.

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DETERMINING THE ABSOLUTE SALT CONTENT OF SOILS BY MEANS OF THE FREEZING-POINT METHOD

By GEORGE J. BOUYOUCOS, *Research Associate in Soils*, AND M. M. MCCOOL, *Professor of Soils, Michigan Agricultural Experiment Station*

When the idea was first conceived of using the freezing-point method (*3*)[1] for measuring the concentration of the soil solution directly in the soil mass, the first problem which was desired to investigate was the absolute salt content of soils. It was thought that if the method proved successful it would afford a unique and excellent means of determining the absolute salt content of soils and thus yield very important and fundamental data on the comparative absolute salt content of soils. When it was discovered, however, that the soils cause water to become unfree and that this unfree water influenced greatly the concentration of the soil solution (*2*), then a direct comparison of the absolute salt content of soils had to be abandoned, and the investigation was confined to determining the actual concentration of the soil solution of a soil at any given moisture content. In this case it did not matter if the unfree water influenced the concentration as long as it was the actual concentration which existed in the soil solution.

It was realized, however, at the very beginning that for comparative studies the error caused by the unfree water was greatly minimized when a high moisture content was employed. For making a comparison, therefore, of the effect of application of salts upon the concentration of the soil solution (*3*, *4*) for determining the lime requirement of soils (*1*), and for measuring the velocity of the reaction between soils and chemical agents (*5*), high moisture content or an excess of water or solution were employed. In studying the diffusion of salts in soils McCool and Wheeting (*8*) also employed a high moisture content in making freezing-point determinations.

On account of the rather small concentration of the soil solution of natural-normal soils at very high moisture content, however, no attempt was made at the beginning to make a direct comparison of the absolute salt content of soils. It was feared that on account of this rather small concentration and on account of the influence of the unfree water, the results would not be dependable, and possibly misleading. If the concentration of the soil solution were rather high at the high moisture content, any small errors that might enter in the determination would probably not have been serious.

[1] Reference is made by number (italic) to "Literature cited," p. 336.

In conducting an investigation during the past year and a half to study the rate and extent of solubility of soils by means of the freezing-point method, it was noticed that when different classes of soil were washed until their soluble salt content was greatly reduced, their lowering of the freezing point was practically identical. For instance, the freezing-point lowering of heavy sandy loams, loams, clay loam, and clays would be about 0.007° C. and that of sands and light sandy loams about 0.005° C.

This identical depression of the different classes of soil suggested at once the idea that at a comparatively high moisture content the influence of the unfree water on the concentration of the soil solution was practically negligible, if not entirely absent. This idea led immediately to the belief that at a high moisture content or in excess of water the freezing-point method could be used to determine the absolute salt content of all normal soils with a high degree of accuracy, and thus afford a comparison of their relative absolute salt content. This belief has been amply confirmed.

There appeared one factor, however, which was thought might prevent the realization of this method, and that is the effect of air-drying upon the water soluble material of soils. It has generally been believed that air-drying causes an increase in the quantity of the water soluble material of soils. It was thought, therefore, that if air-drying did exert this influence to any appreciable extent then the method could not be used, at least very conveniently, as the procedure required the soils to be dry. The recent work of Hoagland (7), however, made it very probable that air-drying has practically no effect upon the concentration of the soil solution.

Since it was discovered that at a high moisture content the concentration of the soil solution could be determined by means of the freezing-point method with a very high degree of accuracy, it was decided to investigate the influence of air-drying upon the water soluble material of soils. The problem was investigated as follows: Samples of different classes of soil were taken from the field and washed with distilled water until practically all their free soluble salts were eliminated. As a rule, a 100-gm. sample was washed, by the percolation process, with 500 cc. of water. A portion of the washed sample was placed in the freezing tube and its freezing-point depression determined. The remaining portion was placed in the room or in the sun and allowed to dry. When thoroughly dried, 15 gm. of it were weighed out and poured in the freezing tube containing 10 cc. of distilled water and its freezing point lowering determined as before. Care was always taken to have the moisture content in both cases about the same. The study involved a large number of soils representing many types and all classes. In Table I are presented the results from a few representative soils employed.

TABLE I.—*Effect of air-drying upon the freezing-point lowering of soils*

Soils.	Natural soils before washing.	Natural soils immediately after washing.	Natural soils after washing and air-drying.
	°C.	°C.	°C.
California Okley fine sandy loam	0.027	0.006	0.006
California Yolo fine sandy loam	.020	.006	.006
California Hanford fine sandy loam	.033	.007	.007
Michigan sandy loam	.035	.005	.006
Michigan silt loam	.031	.010	.010
Wisconsin Carrington silt loam	.038	.009	.010
Wisconsin Miami silt loam	.030	.010	.011
Michigan heavy silt loam	.040	.010	.011
Kentucky clay loam	.040	.010	.011
Michigan clay loam	.040	.010	.010
California Ramona clay loam	.041	.010	.010
Michigan heavy clay loam	.048	.010	.012
Wisconsin Superior clay	.031	.010	.010
Minnesota Superior clay	.035	.010	.010
Texas Crawford clay	.040	.010	.011

An examination of the data in Table I shows at once that the freezing-point depression of the soils did not increase by the process of air-drying. It will be seen that the depression is practically the same after drying as before drying, the difference is only about 0.001, which is within the experimental error. The conclusion is inevitable, therefore, that air-drying, at least once, does not increase the quantity of the soluble material of soils.

From the above results it is also seen that the rate of solubility of soils is very slow, or that saturation is not attained very rapidly as has been claimed (*6, p. 55-56*). It took at least three hours and in some cases 24 hours for the soils to dry, and yet hardly any material went into solution during this time. These results are overwhelmingly substantiated by the very extensive investigations, to be reported later, on the rate and extent of the solubility of soils, in which it is shown that the depression of soils at optimum moisture content increases only about 0.003° C. during the first 10 days, or from 0.010° to 0.013°, and that this depression increases to about 0.025° at the end of 30 days, and to about 0.040° at the end of 60 days.

As a result of the foregoing facts it is firmly believed, therefore, that the freezing-point method can be used to determine the absolute salt content of soils at high moisture content with a very great degree of accuracy.

The procedure which has been adopted for making a comparative study of the absolute salt content of all kinds of soils is as follows: The soils are allowed to air-dry if freshly taken from the field. Then a 15-gm. sample of soil is taken and poured into the freezing tube containing 10 cc. of distilled water. The soil is stirred, usually by shaking, allowed to stand for a few minutes, and its freezing-point depression determined.

For accomplishing the latter the tube is placed directly in the ice mixture having a temperature of about −2.5° C., and the soil is stirred constantly with the Beckmann thermometer until the temperature falls to about 1 degree above the zero point of the thermometer. Then it is allowed to remain undisturbed until the temperature falls to about 0.5 degree below the zero point, when the soil is again stirred with the thermometer in order to cause solidification to take place. As soon as solidification begins, the tube is at once taken out of the ice mixture and placed in the air jacket in the same bath. The soil is gently stirred and the thermometer gently tapped and the freezing point read by means of a lens. By this procedure it takes only about 10 minutes to make a freezing-point determination.

The proportion of 10 cc. of water to 15 gm. of air-dry soil has been found to be the best, as it gives a sufficient amount of excess water to practically all classes of soil, except peat, muck, and some soils containing an exceedingly high content of organic matter. Where a comparison of the salt content of all kinds of soil (with a few exceptions) is desired, therefore, the above proportion is the best. On the other hand, where a comparison of the salt content of light soils is desired, the proportion of 10 cc. of water and 20 gm. of soil is more advisable. The best ratio is that which gives a sufficient amount of excess water and at the same time a comparatively high concentration. In the case of alkali soils a ratio of one of soil to five of water may be used.

The salt content of soils can be expressed both in degrees of depression and in parts per million of solution. The latter can be easily and conveniently calculated by following the formula that a depression of 0.004° C. is equivalent to 100 p. p. m. of solution (*4*).

In determining the salt content of natural soils from the field the following factors should always be taken into consideration in interpreting the results: (1) Season of the year in which the soil is collected; (2) amount of rainfall and length of period elapsed after the rainfall before sample is collected; (3) temperature and rate of evaporation; (4) cultural conditions of the field, whether cropped or uncropped; and (5) depth of collecting sample, etc. All these factors play a very great part, if not the controlling rôle, in the amount of salts found in soils. Thus, for instance, in the early spring, when the soils are thoroughly washed by the melted snow and the spring rains and when the rate of solubility and nitrification are slow on account of the low temperature, the salt content of all soils, including the richest soils, is exceedingly small, amounting, as a rule, to a depression of only about 0.010° C., or 250 p. p. m., when the ratio of water to soil is about 1 to 0.7. In summer time after a long drouth the salt content of bare soils at the surface is quite high, amounting in some soils to a depression of 0.200° C., or 4,878 p. p. m. of solution, when the ratio of water to soils is 1 to 0.7. Immediately after a heavy and prolonged rain, however, all these salts are

leached away, at least from the upper layers, and the salt content falls again to the depression of about 0.010° C., or 250 p. p. m. at the surface. In the cropped soils the salt content is, as a rule, quite low, amounting to a depression of only about 0.010° C., or 250 p. p. m. at the various depths, as compared to a depression of about 0.200° C., or 4,878 p. p. m. in adjacent bare soil at the surface. Again, after a long drouth the salt content of nearly all bare soils varies considerably at different depths. The variation may range from about 5,000 p. p. m. at the surface to about 250 p. p. m. at the third inch. All these facts find ample confirmation in the data presented in Table II, which shows the salt content of a certain number of soils under the conditions described above. The salt content is expressed both in freezing-point depression and parts per million of solution.

TABLE II.—*Salt content and freezing-point lowering of soils at different seasons, at different periods, under different cultural conditions, and at different depths*

Description of soils.	May 10; after a rainfall.		May 18; 8 days after a rainfall.		June 12; 12 days after a rainfall.		July 1; after a rainfall.		July 10; 10 days after a rainfall.	
	°C.	P. p. m.	°C.	P. p. m.	°C.	P. p. m.	°C.	P. p. m.	°C.	P. p. m.
(1) Sand, bare, 2 inches	0.010	250	0.015	375	0.016	400	0.010	250	0.018	450
(2) Sandy loam, bare, 2 inches	.011	280	.017	425	.033	825	.010	250	.035	875
(3) Sandy loam, bare, 2 inches	.011	280	.017	425	.038	950	.012	300	.050	1,250
Same as No. 3, under wheat, 2 inches	.009	225	.011	280	.010	250	.012	300	.012	300
(4) Sandy loam, bare, 2 inches	.011	280	.016	400	.028	750	.012	300	.033	825
Same as No. 4, under hay, 2 inches	.010	250	.012	300	.013	317	.011	280	.013	317
(5) Heavy loam, bare, 2 inches	.012	300	.018	450	.028	700	.013	317	.045	1,175
(6) Heavy clay loam, bare, 2 inches	.012	300	.019	475	.048	1,200	.013	317	.065	1,625
Same as No. 6, bare, at surface	.012	300	.028	700	.067	1,700	.012	300	.130	3,250
Same as No. 6, under oats, 2 inches	.011	280	.013	317	.015	375	.011	280	.012	300
(7) Clay, bare, 2 inches	.011	280	.015	375	.018	450	.011	280	.025	675
Same as No. 7, under sod, 2 inches	.010	240	.012	300	.013	317	.010	250	.013	317
(8) Clay, bare, 2 inches	.011	280	.015	375	.020	500	.011	280	.027	675
Same as No. 8, bare, at surface	.011	280	.022	550	.030	750	.011	280	.035	875

It is evident, then, that the salt content of soils is controlled by many external factors, and that when these factors are not taken into consideration in the collection of the soil samples and in the interpretation of the results, very erroneous conclusions will inevitably be drawn as to the comparative salt content of soils. Yet it is surprising how many investigators in the past have overlooked or ignored these factors and

and have collected samples of soils irrespective of season, rainfall, condition of soil, date, and uniformity of sampling, etc., and then tried to compare the absolute salt content of these soils.

By being able now to determine the absolute salt content of soils, the value and usefulness of the freezing-point method are increased tremendously. This method is now able to accomplish at least two very important and fundamental things: First, to determine the actual or real concentration of the soil solution as it actually exists in the soil from a very low to any maximum moisture content, and second, to determine the absolute salt content of soils at a high moisture content. It seems to be the best, most unique, and most accurate method we have to-day for accomplishing these purposes.

SUMMARY

In the present paper the freezing-point method is presented as an excellent means for determining the absolute salt content of soils with a very high degree of accuracy. Formerly the method could determine only the actual concentration of the soil solution as it existed in the soil at different moisture contents, but now the method has been developed to measure also the absolute salt content of soils and thus afford an accurate comparison of the absolute salt content of soils.

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SWEET-POTATO STORAGE-ROTS

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INTRODUCTION

The production of sweet potatoes (*Ipomoea batatas*) in the United States in 1917 was estimated to be a little over 87,000,000 bushels, valued at more than $95,000,000 (Monthly Crop Report, December, 1917). Of this quantity probably about 50,000,000 to 55,000,000 bushels were placed in storage either to be put on the market or to be used for home consumption throughout the winter months. While no accurate data can be given, it is estimated that only about 33,000,000 to 38,000,000 bushels of the stored crop were actually consumed; the remainder were destroyed by storage-rot organisms before they reached the market. Based on the estimated average price of $1.10 per bushel for December, 1917, the loss would be approximately $18,000,000.

This article deals with the rots caused by 17 fungi responsible for the loss of sweet potatoes in storage. Several of these organisms are of minor importance, the largest percentage of decay being caused by only a few very destructive forms. In view of the fact that we are dealing with the underground parts of the plant and the method of storing the roots, it is only natural that a large number of fungi could be isolated. Many of these proved to be only saprophytes; others were able to cause decay only under especially favorable conditions.

The first phase of the problem consisted in making a collection of the organisms found in the decayed roots or in the lesions of stored potatoes. Accordingly about 40 different fungi and several species of bacteria were isolated. Twenty-five of these fungi were tested out to determine whether they were secondary invaders, saprophytes, or weak parasites capable of causing decay under certain conditions. Of this number 17 were found to exhibit varying degrees of parasitism, the remaining 8 being regarded as secondary invaders or as saprophytes. Some of the forms most frequently isolated, in fact, almost always present, were found to be weak parasites or strictly saprophytes. It was soon discovered that two and often more forms could be isolated from the same rotted root. Which of these was the primary cause of the decay could only be determined by inoculation with pure cultures. The isolation of

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a single fungus in pure culture was no guaranty that it caused the rot, since it was found that the causal fungus often died out early and a secondary form, the only one isolated, took its place. This was especially true of decay caused by *Rhizopus nigricans*. Again a fungus was isolated in pure culture from freshly decayed spots or from rotted ends of the potato, and persistently failed to cause decay when inoculated into healthy roots. *Fusarium oxysporum* is a notable example. This organism has been isolated literally hundreds of times, and the writers believe that it is one of the most common endrot organisms, but they have failed to prove it responsible for the decay.

Some of the organisms which the writers are classing as storage-rot fungi are rarely isolated, and under natural conditions evidently are responsible for very little loss. However, they will produce decay when inoculated into healthy potatoes, held under suitable conditions of temperature and humidity, and protected from the competition of other fungi. They are mostly slow-growing forms and it may be possible that they are crowded out by the more rapidly growing saprophytes. It is these organisms the writers propose to term the "minor rot-poducing fungi."

The study of sweet-potato storage-rots was begun in 1912. It has been pushed continuously ever since as a major problem of the sweet-potato disease work, except for a few months in the summer when press of field work, or the want of potatoes, made it imperative to suspend the work temporarily.[1]

A mass of data has accumulated during the period of five years that these investigations have been under way. While it can not be said that the problem is finished it is felt that the results so far obtained justify publication at this time.

METHOD OF TESTING PARASITISM

Contrary to the earlier predictions of the writers, the parasitism of most of the organisms was difficult to demonstrate. Organisms frequently isolated and always from the same type of decay, and of which there could be little question of their causal nature, would not produce rot by the ordinary simple moist-chamber methods nor consistently under storage-house conditions. We were therefore forced to turn our attention to an inquiry into the conditions required to permit decay. It has been notable throughout the entire course of the work that those organisms which appeared unquestionably responsible for decay under natural conditions would not cause rots when inserted into the host unless special methods of technic were employed.

[1] Mrs. Ethel Field Tillotson was associated in this work until the time of her retirement in 1915. She is entitled to much credit for painstaking work in the preliminary study of these diseases and especially for the development of technic for studying some of the rots. During the winter of 1915 and 1916 Mr. C. W. Carpenter entered upon the work, but after a few months left to engage in pathological work elsewhere.

The initial experiments consisted mainly in smearing spores from pure cultures, or hyphæ of the sterile fungi, on unwounded or on cut surfaces of healthy potatoes. They were then placed in moist chambers with wet filter paper in the bottom and under the lid and kept on a table in the laboratory. Almost without exception the potatoes remained sound. These preliminary experiments were repeated, but differed in that each potato after inoculation was wrapped in moistened filter paper and then in oiled paper. The results again were negative, a few being infected with softrot but no more than in the controls.

A considerable number of tests were made with the different organisms by inoculating sterile cut blocks of raw sweet potatoes in test tubes with a little water added. While the results so obtained were not entirely satisfactory, they suggested the more promising rot-producing organisms. Some of these inoculated tubes were placed in the various chambers of the Altmann thermostat, the temperature of which ranged from nearly zero to 40° C. It was shown thereby that temperature was one of the controlling factors, and other experiments showed that humidity was equally important with most organisms. The importance of humidity suggested at this stage of the work that although the potatoes were in a nearly saturated atmosphere in a moist chamber the spores were not suspended in sufficient moisture to permit germination. It is a fact easily recognized that moisture may condense on a damp chamber and yet the potatoes remain dry. Evidently potatoes, as already reported (*18*),[1] absorb the moisture from the surface, leaving the spores without sufficient water in which to germinate. This difficulty was somewhat overcome by pouring sterile water in wells about 1 cm. deep and about 1 cm. in diameter made in the potato with a cork borer. Spores were suspended in the water and the top sealed over with a cover slip set into vaseline. It was hoped by this means to retain the moisture long enough to allow the spores to germinate. This practice yielded better results than any previously tried, but was by no means satisfactory or consistent, the water being often absorbed before the spores had time to germinate. In the belief that previously germinating the spores might be a solution of the difficulty, a decoction from sweet-potato roots was made as follows: 500 gm. of sweet potatoes were finely cut into 1,000 cc. of distilled water, the whole steamed for one hour, and then filtered through gauze. If needed for immediate use, 2 cc. of this solution were put into test tubes and autoclaved for 15 minutes at 11 pounds' pressure. Generally a considerable quantity of stock solution was prepared for future use. This was put into large flasks and steamed for 20 minutes on three consecutive days. When needed, 2 cc. of this stock solution were transferred to test tubes, which after autoclaving as above were inoculated with the spores of the fungus under investigation. After about 24 hours, and rarely

[1] Reference is made by number (italic) to "Literature cited," p. 366-368.

over 48 hours, this decoction together with the mycelium, which often formed a pellicle, was poured into a well in the potato made as described above and sealed over with a cover slip set in vaseline.

The inoculated potatoes were then put into moist chambers with wet filter paper in the bottom. Inoculations by this method were usually successful, except for organisms that have been classed as strictly saprophytes. By this method sufficient moisture and nutrient substances were supplied to give the fungus a start. The method was later modified somewhat to facilitate manipulation. Instead of covering the well with a cover slip, the hole was plugged with cotton. If tightly plugged, enough of the decoction was retained to serve the desired purpose even though the specimen was turned with the well to one side or downward. Coupled with the proper temperature conditions, such extreme methods usually gave positive results with organisms that otherwise consistently gave negative ones. It may be argued that where such extreme measures are required the organism should not be classed as a rot producer. The only answer to this is that in our hands they are rot producers under artificial conditions only when subjected to this test and most of the organisms studied require such a method. This applies to some of the most common forms consistently isolated from a rot of a definite type, and of which there can be little question of their causal relation.

SOFTROT AND RINGROT

There are two storage-rots of sweet potatoes caused by *Rhizopus nigricans* Ehrbg.: Softrot and ringrot. The former has long been known as the softrot of sweet potatoes in storage. Halsted (*12*), who, we believe, was the first to recognize it as such carefully described it in 1890. In 1892 a rot of quince (*13*) was attributed by him to the same fungus. Since that time there have been other observations and experiments which show that *R. nigricans* is responsible for rots of fruits and vegetables under suitable conditions. Behrens (*3, p. 515–516*), Wormald (*41*), and Hanzawa (*16*) have all found it causing a rot of tomatoes. In 1908 Morse (*28*) attributes a rot of fruit to it, and Orton (*29*) a year later found the same fungus associated with the "leak" of Irish potatoes in the San Joaquin Valley of California. Edgerton (*10*) attributes a heavy loss of figs to the same fungus. In 1916 Stevens and Peterson (*32*), in a study of strawberry fungi, mention *R. nigricans* as the cause of considerable loss to the berries at their destination. A more extensive study of this same trouble was later made by Stevens and Wilcox (*33*), who conclusively proved the parasitic nature of the fungus and studied the factors which contribute to its destructiveness. While this brief survey of the literature shows *R. nigricans* to be a relatively common rot-producing organism of various hosts, it is best known as the cause of softrot of the sweet potato, to which it probably causes more monetary loss than to all the other crops combined. Compared with other organ-

isms causing decay of sweet potatoes in storage, it is certainly the most destructive and probably causes more loss than all the others combined. In fact, there could be no doubt in the mind of anyone who had carefully observed and studied softrot under natural conditions that *R. nigricans* was responsible for it. However, to determine the conditions required to bring about decay and consistently to produce it artificially is quite another matter.

Ringrot, now known to be caused by *R. nigricans*, was originally thought by Halsted (*14*) to be due to *Nectria ipomoeae* Hals., but was later shown (*35*) to be caused by *R. nigricans*.

CHARACTERISTIC SYMPTOMS

The so-called softrot begins at one of the ends of the potato, occasionally in the middle, and progresses rapidly through the healthy tissue. Only four to six days are required to complete the destruction of the entire potato at room temperature. This time may be shortened by higher temperatures, and correspondingly lengthened by lower temperatures. Humidity seems essential only in so far as it contributes to the initial infection of the potato. Experiments have shown that decay, after once having started, will continue, though slightly retarded, even in an atmosphere almost entirely free of moisture, the fungus apparently being able to obtain the needed moisture from the host. These results are in strict accord with those obtained with strawberries by Stevens and Wilcox (*33*). The potatoes are at first rendered very soft and stringy, water often dripping out of the potato when broken open. It has a characteristic mild yeast odor at first, followed by a wild-rose to rose-geranium odor later. At the outset the color of the tissue is not changed, but later it turns a cinnamon to chocolate-brown. If the epidermis of a decayed potato is ruptured, the sporangiophores and sporangia develop in great numbers in the air (Pl. 21, A). On the escape of moisture the potato dries up and finally becomes dry and mummified. Observed in this stage it is often classed as a dryrot.

Usually softrot sets in soon after the potatoes are put in storage and continues more or less throughout the entire storage period, depending largely upon weather conditions and the management of the storage house. It is believed that the rot does not depend to any extent upon the amount of sugars and starch present; evidence in support of this theory will be presented later. Softrot is largely a storage trouble, though it is occasionally found in the field at digging time in wet soils, especially those containing a considerable amount of organic matter.

Ringrot differs from softrot only in that the infection occurs at one or more places between the two ends. It progresses around the potato forming a ring or collar, by the drying out and subsequent shrinking away of the rotted tissue, as shown by Plate 21, B. The extent of the rot varies, being in some cases 1 or 2 inches in width, and may extend

½ inch in depth, or entirely through the potato. It may dry up after completing the ring, or it may advance toward the two ends and finally complete the destruction of the entire potato. As many as three such rings have been seen on a single potato, both in storage and in the field. Taubenhaus claims that it is only a storage-rot, but the writers have found it more prevalent in the field than softrot.

DISSEMINATION

In view of the general prevalence and wide distribution of the fungus, it is doubtful whether dissemination of *R. nigricans* is ever necessary to insure infection. Although the storage house may have been thoroughly disinfected, it is likely that the spores are carried in on the potatoes, where they remain dormant until conditions are favorable for their germination and infection of the host. Such an environment is soon provided after the sweet potatoes reach the storage house. During the sweating and curing period, when the temperature is high, a certain number of potatoes are softrotted. Upon the rupture of the epidermis sporangia form in great abundance on the surface. The spores are then easily distributed by insects which frequent such rotted potatoes, by settling in the bins, and possibly by air currents. A certain amount of spore dissemination may also be brought about by workmen preparing the potatoes for market. That the disease is communicable is evident from the fact that often a number of potatoes in contact with each other have rotted at about the same time. The rotting of a number of potatoes in contact is much more common in the center of the bin, where ventilation is poor. Individual rotted potatoes on the top of the bins and elsewhere, however, are frequently found. Experiments have shown that the hyphæ of *R. nigricans* die relatively soon. The spores, on the other hand, remain viable for several months.

INOCULATION EXPERIMENTS

It has already been stated that there could be little doubt in the mind of anyone who had studied softrot and ringrot under natural conditions that *Rhizopus nigricans* had caused it. Taubenhaus (*35*) and Taubenhaus and Manns (*37*) published results in which they claim to have brought about the complete decay of the potatoes and the formation of mature sporangia on the surface in 15 hours by smearing the spores dry on the surface of the potatoes in a moist chamber. Their results are not supported by those of the writers. With several hundreds of transfers of *R. nigricans* on various media and on sweet potato decoction, the best medium so far tried, 24 to 48 hours were required to produce sporangia at room temperature. Ames (*1*) who investigated the temperature relations of *R. nigricans* among other storage-rot organisms, found that the shortest time in which the spores could be germinated was 5½

hours at a temperature of 38° to 41° C. No germination occurred at 42°. In general, she found that the length of time required to germinate the spores increased as the temperature decreased. At 25° and 20°, temperatures more nearly approximating room temperature, 13 and 16 hours, respectively, were required to germinate the spores.

In a large number of experiments the writers have been unable to verify the results of Taubenhaus (*35*) and Taubenhaus and Manns (*37*) by the method they used. Neither have satisfactory results been obtained by inserting spores and hyphæ deep into healthy tissue and confining the potatoes in a damp chamber. Potatoes inoculated by wounding and wrapped in wet filter paper and then in oiled paper to retain the moisture would not give positive results. Potatoes cut in two lengthwise and the spores and hyphæ confined between the two halves would not rot any more than the controls, even when wrapped in moist filter paper and oiled paper and subjected to the environment of a moist chamber. Spores suspended in water in a well made in the potato and sealed over by a cover slip would not give consistent results. Chilling the potatoes or bruising before inoculating likewise failed to give anything like conclusive results. Experiments of this type in large numbers have been made on potatoes of all sizes taken from storage houses at different times during the storage period and always with negative results. The writers have even failed to get results by cutting off the rotted end from a softrotted potato and inserting bits of the diseased tissue from the rotted part into the sound portion.

Similar results have been obtained independently by Dr. Heinrich Hasselbring, of the Bureau of Plant Industry, who has permitted the writers to use his results. He made literally hundreds of inoculations from pure cultures of *Rhizopus nigricans* into jagged wounds made with a scalpel. The potatoes were then kept in moist chambers or under bell glasses at room temperature. Now and then a potato rotted, but not enough to justify the conclusion that consistent infection had been obtained.

Not until the writers had developed the "well method" described on page 339 could they rot the potatoes at will. A 24-hour growth of *Rhizopus nigricans* in sweet-potato decoction poured into a "well" and protected against too rapid drying out would almost always result in rotting the potato. By this method rot has been produced in large as well as small potatoes and in sprouted as easily as unsprouted. In view of the fact that stored sweet potatoes could be rotted with equal ease at any time of the storage period by this method, it would seem that the sugar content of the potatoes, if contributory to infection, certainly was not a controlling factor. Hasselbring and Hawkins (*24*), in an exhaustive series of experiments, have shown that at digging time the starch content is high and the sugar content of the sweet potato is low. From the beginning of the storage period the percentage of starch gradually

decreases and the sugar content increases up until about March, when there is a slight reversal of the process. They have further shown that about March or April, when the sugar content is highest, the water content is not higher, but actually lower. There is evidently enough sugar during any of this time to supply the needs of the fungus. In fact, sweet potatoes growing in the field have been successfully infected with *R. nigricans*, and it is a common thing to see naturally infected potatoes in the field at digging time and in the hotbed in the spring. The writers have been able to infect freshly dug potatoes at will, as well as potatoes in storage as late as June.

BLACKROT

We owe our first knowledge of blackrot, caused by the fungus *Sphaeronema fimbriatum* (E. and H.) Sacc., to Halsted (*12*), who found it causing much damage to the sweet-potato crop in New Jersey. In 1890 he published a very good account of the disease, which he attributed to *Ceratocystis fimbriata* E. and H. This name was later changed to *Sphaeronema fimbriatum* by Saccardo (*31*). The following year Halsted and Fairchild (*15*) published the results of an excellent morphological study of the blackrot organism. In fact our knowledge of this fungus has been little advanced since the publication of their work. The sclerotial bodies which were thought by them to be a stage in the development of the blackrot fungus were later shown (*34*) to be a separate organism. On the whole, however, the blackrot fungus was the best known, and its life history and morphological characters better understood, than any of the other organisms causing sweet-potato diseases. Chester (*6*), contemporaneously with Halsted, came to the conclusion that the causal fungus was carried over in the soil. That blackrot is important as a field disease, a storage-rot, or both, and is widely distributed may be judged from the writings of Price (*30*), Duggar (*9*), Townsend (*39*), Wilcox (*40*), Carver (*5*), Barre (*2*), McClintock (*26*), and others, all of whom mention it as a field disease or in connection with storage-rot. It therefore seems imperative to discuss briefly this disease as it affects the plants in order to show how it becomes so destructive in the storage house.

If blackrotted potatoes are bedded, the slips produced therefrom will almost invariably have blackrot or "blackshank," as the disease is sometimes called. It is characterized by blackrotted areas of varying extent on the underground part of the slip. Plate 22, A, is reproduced from a photograph of a typical hotbed infection of a young plant, and Plate 22, B, shows a bedded potato the slips of which have been killed by the blackrot organism. The fungus not only reaches the hotbed by being carried there on the seed potatoes, but it will live over in the soil of the old hotbed or in other soils where infected plants have been grown. Diseased plants, if set in the field, serve as a source of infection to the new crop. It is

these potatoes, infected in the field, which carry the disease to the storage house. Usually when the potatoes are put in the storage house they show little or no evidence of blackrot. The potatoes with visible blackrot spots are few, and such are generally thrown out. On the other hand, those with infections too small to be seen pass along into the storage house, where they continue their development. In the course of a few weeks the spots attain a diameter of an inch or more, and the fungus, under suitable conditions, has fruited abundantly. The spores are scattered about the house on the bodies of insects, by the settling of the potatoes in the bins, and probably by currents of air, and by other means, such as picking the potatoes over and preparing them for the market. In some houses a large percentage of the potatoes have blackrot, though at the time they were put in storage they showed no evidence of it. Plate 23, A, shows a potato infected with blackrot and Plate 23, B, the same potato two months later. This potato was kept in an ice box at a temperature of 10° to 13° C. During the two-month period the spots had developed so as to envelop nearly the entire potato.

That blackrot is transmitted through the soil was demonstrated by bedding a large number of healthy potatoes in soil infested with blackrot. The potatoes used in the experiment were carefully examined for soundness, and then disinfected in mercuric chlorid (1:1,000) for 10 minutes. Potatoes from the same lot, bedded in disease-free soil in the same hotbed, were used as controls. The slips from blackrotted soil were set alongside the control plants in a field where blackrot was not known to occur. Only a few of the slips when set out showed blackrot infection. About 25 bushels of potatoes were produced from these slips. When the potatoes were dug, a few had visible blackrot spots on them and were discarded. The apparently sound potatoes (25 bushels) were mixed with sound potatoes in a 100-bushel bin. When they were removed in the spring, most of the 100 bushels in the one bin had to be thrown out, and a fair percentage from bins on either side. The loss in the adjoining bins was greatest on the side next to the bin containing the blackrotted potatoes. The disease had not been communicated to any extent to other bins in the same house. The potatoes from the control plants stored in another part of the house all remained sound. Further proof that it is disseminated in storage was shown by an experiment in which blackrotted potatoes and healthy potatoes were mixed in a bushel basket and stored. When the potatoes were removed in the spring, all but one of the healthy potatoes were infected with blackrot.

DESCRIPTION OF BLACKROT

Blackrot is characterized by the formation of more or less circular, somewhat sunken, black spots on the surface of the potato. Infection takes place readily through wounds and through the dead rootlets. If

the potato is cut open with a knife and spores smeared on the wound, the organism will cover the entire cut surface in a short time if sufficient moisture is provided. Likewise, if unwounded potatoes in a moist chamber are sprayed with the spores, numerous infections will result, a small rootlet usually being the center of the spot (Pl. 24, A). It is likely, also, that under natural conditions infection takes place in a similar manner with or without wounding. Pycnidia usually develop in the center of the infected area at the point where the fungus entered, or at any place where the epidermis may be ruptured. Under natural conditions there are usually only a few spots on a potato, although in exceptional cases there may be many. Plate 24, B, shows a spot on a potato after several weeks in storage. If kept in storage for several months, the entire potato may be involved and rendered useless for food.

In most infections the fungus penetrates only to the vascular ring, though it has often been isolated in pure culture from the center of the root (Pl. 24, C). Taubenhaus (*34*) claims some resistance for the small roots, but the writers have been able to infect them, and even the rootlets, as easily as the large ones.

Blackrot specimens have been collected or received from every State in the Union where sweet potatoes are grown. It can safely be said that the disease is as widely distributed as the crop itself.

SUSCEPTIBLE VARIETIES

Growers of sweet potatoes are always interested in knowing whether there are any varieties resistant to this or any other disease with which they are concerned. Although no inoculations were made, records have been kept for several years of the varieties infected under natural conditions. These records were obtained either from varieties identified by the Office of Horticultural and Pomological Investigations, Bureau of Plant Industry, or from varieties obtained from that office and subjected to natural infection of blackrot. To this have been added data collected on visits to the various sweet-potato growing sections of the country. The following varieties were found susceptible: Southern Queen, White Yam, Big Stem Jersey, Yellow Jersey, Red Bermuda, Red Brazilian, Florida, White Gilke hybrid, Vineless Pumpkin Yam, Pumpkin Yam, Eclipse Sugar Yam, Porto Rico, Triumph, Yellow Yam, Early Carolina, Miles Yam, Georgia, Pierson, Key West Yam, Nancy Hall, Red Jersey, and an unnamed variety, No. 10950 (Horticultural and Pomological Investigations number). In all, 21 varieties are known to be susceptible to blackrot. As this list includes most of the best known and most widely cultivated varieties of sweet potatoes, it is doubtful whether any of the varieties are resistant to blackrot.

JAVA BLACKROT

Java blackrot, a disease caused by *Diplodia tubericola* (E. and E.) Taub., is probably as widely distributed as the sweet-potato crop itself, and the total loss from this disease is large. It has been collected from every part of the United States, and specimens have been sent to the writers from Cuba, Isle of Pines, Philippine Islands, Japan, Porto Rico, South America, and elsewhere. It can be found in practically every sweet-potato storage house and also in the banks. This disease causes a greater loss in the Tropics and the southern part of the United States than in the northern sweet-potato belt.

Java blackrot was first reported on sweet potatoes in 1896 by Clendenin (7). The specimens on which she observed the disease were sent from Java to the Louisiana Experiment Station in 1894. From what we know at the present time, however, it is likely that this disease had been common in this country long before then, probably ever since sweet potatoes have been cultivated. The fact that it was first reported on sweet potatoes imported from Java is no evidence that it was introduced at that time. We now know that species of Diplodia occurring on various hosts will also infect sweet potatoes. Investigations have shown (36) that *D. gossypina* Cke., *D. natalensis* Ev., and *Lasiodiplodia nigra* Appel and Laub., will all cause a rot of sweet potatoes similar to the rot caused by *D. tubericola*. Furthermore, it has been shown by the senior author (18) that *D. tubericola* from dasheen (*Colocasia esculenta*), *D. gossypina*, *D. maclurae* Speg. and *Diplodia* sp. from mango (*Mangifera indica*) will produce a rot of sweet potatoes identical with the rot produced by *D. tubericola* isolated from sweet potatoes. Further evidence of the cosmopolitan nature of these organisms has been submitted by Meier (27), who found that *D. tubericola* from sweet potato would cause the stem-endrot of the watermelon (*Citrullus vulgaris*).

It is therefore probable that species of Diplodia from other hosts, if inoculated into sweet potatoes, dasheens, or watermelons, would cause similar rots.

DESCRIPTION OF JAVA BLACKROT

Diplodia tubericola rots sweet potatoes very slowly. Under laboratory conditions there is little or no evidence of decay for a week or 10 days, and usually 4 to 8 weeks are required to entirely destroy a potato. The pycnidia, which ordinarily develop in great abundance, generally appear at the end of one month on the part of the potato first decayed. They are externally coal black, crowded closely together or confluent, and microscopically suggest minute domelike elevations on the surface. Unlike some of the fungi of this group, many pycnidia are completely buried, the spores escaping only after maceration or disintergation of the host. The tissue is first rendered brown in color, but later becomes coal black and hard. Concomitant with the loss of water, the root shrinks, eventu-

ally becoming mummified (Pl. 25, A). The spores may be of three types and sometimes all three may be found in the same pycnidium. In the young pycnidium they are usually hyalin and 1-celled, and occasionally this is the only type found; but usually a little later the hyalin spores turn dark, and may or may not be septate. In the old mummied potato the 2-celled dark spores predominate, but are intermixed with a few 1-celled dark and a few 1-celled hyalin spores.

INOCULATION EXPERIMENTS

The first inoculation experiments were made on January 16, 1914, when spores and hyphæ were inserted into a wound at the end of eight healthy roots, four with *Diplodia tubericola* from dasheen and four with the same organism from sweet potato. These potatoes were kept in an uncovered vessel in the laboratory. This method was followed because preliminary experiments showed that better results could be obtained by exposing the inoculated roots to the dry conditions of the laboratory room than in a moist chamber. Just why this should be has not been determined. On February 18, six of the potatoes were partially rotted and on March 12 all but two, which remained sound, were completely decayed, *D. tubericola* being recovered in pure culture from each. On May 8, eight potatoes were inoculated with *D. maclurae* and placed in an uncovered moist chamber. One of these potatoes remained sound, but the others were completely decayed by July 11.

On September 2, 1914, twelve sweet potatoes were inoculated with *Diplodia gossypina*. Six were inclosed in a damp chamber with moist filter paper in the bottom, and six were placed in an open receptacle. On October 15, in the open vessel the results were as follows: Two were completely rotted, two one-fifth rotted, and two sound. The fungus was recovered from the four decayed potatoes. In the moist chamber one was completely rotted, one one-third rotted, and four sound. From one of the rotted potatoes *D. gossypina* was isolated, and from the other an unknown fungus.

On January 5, 1915, six sweet potatoes were inoculated with *Diplodia zeae* (Schw.) Lev. All remained sound.

On January 14, 1915, ten sweet potatoes were inoculated with *Diplodia tubericola* from sweet potato. Five were immediately placed in an incubator (34°–35° C.), and five in an ice box (12.2°–13.5° C.). On February 8 two potatoes in the incubator were entirely rotted, and one remained sound. On February 23 one of the two remaining potatoes was half decayed and the other entirely decayed. There was no evidence of decay in the potatoes in the ice box on January 25, but by January 29 two had been completely rotted by *Rhizopus nigricans*. By March 31 two were partially rotted, and *D. tubericola* was isolated in pure culture. The remaining potato was completely decayed, and *Alternaria* sp. was obtained in pure culture from it. The best results were obtained at the higher temperature.

On March 1, 1915, six sweet potatoes were inoculated with *Diplodia tubericola* from dasheen and kept in an open receptacle. One potato was decayed by *Rhizopus nigricans*. By June 1 two were entirely decayed, and *D. tubericola* was isolated from them. Three remained sound.

The question has frequently been raised whether or not *Diplodia tubericola* attacked the plants in the field and was carried on the infected roots to the storage house where it further developed. A number of half-grown plants were inoculated in the field by inserting spores and hyphæ of *D. tubericola* from sweet potatoes into the stem near the hill. When the potatoes were dug, none of the plants showed any evidence of disease. The potatoes from all the inoculated plants were stored together, but none of them were decayed by *D. tubericola*. From these results and numerous field observations it is concluded that this organism does not attack the plants in the field, and consequently could not transmit the disease to the roots.

DRYROT

Diaporthe batatatis (E. and H.) Harter and Field causes what is commonly known as the dryrot of sweet potatoes. It was first reported by Halsted (*12*) in 1890, who attributed the disease to *Phoma batatae* E. and H. Later the disease was more exhaustively studied by Harter and Field (*21*), who obtained in pure culture the perfect stage of the causal organism to which the name "*Diaporthe batatatis*" was given. The imperfect stage of the fungus is the only one found on the potatoes from the storage houses or field material. They reported the occurrence of the disease in the States of North Carolina, Texas, New Jersey, Virginia, Mississippi, Alabama, and Indiana. Since then it has been collected in many other States, or diseased specimens have been received from them, so that it can be safely said to have a wide distribution. In 1917 *D. batatatis* was isolated from material from the Isle of Pines and when inoculated into healthy plants on the Potomac flats near Washington D. C., produced characteristic symptoms of the disease. This strain, while identical morphologically, is a more vigorous parasite than any isolated from material collected in the United States.

Although this organism is quite prevalent, the total loss from the disease it produces is relatively small, the loss being more in storage than in the field, though it is occasionally found on the slips in the hotbed. Like many other fungi, it will grow as a saprophyte and is for this reason found also as a secondary invader. Inoculation experiments have shown that it is quite capable of causing decay.

Diaporthe batatatis usually enters the potato from the stem end and progresses slowly downward. It grows very slowly, requiring 4 to 8 weeks to entirely destroy a potato. In this respect it resembles *D. tubericola*. Infected potatoes become much shrunken and wrinkled and finally mummified (Pl. 25, B). The surface, beneath which the tissue

is carbonaceous to coal-black, is covered with small elevations, a millimeter or so in diameter lying close together, in which the pycnidia are embedded.

FOOTROT

Footrot, a disease caused by *Plenodomus destruens* Harter, is one of the most serious diseases of the sweet-potato crop, once it has become established. It also occurs in storage and is carried over mostly on the potatoes held for seed. The results obtained by the writers confirm those of McClintock (*26*), who found that field infection, while not entirely lacking, is relatively small, the disease being carried to the field mostly on the slips. During the early part of the season the fungus grows slowly, but in July and August, when warm weather comes on, it progresses rapidly. It has been shown (*17*) that the footrot organism invades the stem of the plant near the ground and grows down into the potatoes, causing a decay beginning at the attached ends (Pl. 26, A). This decayed portion is generally slight at digging time and, therefore, easily overlooked. Occasionally it may involve an inch or more of the end of the potato, in which case it would probably be thrown out. Potatoes but slightly decayed may find their way into storage, where the development of the disease would be continued. By bedding time a considerable percentage of potatoes are thrown out in a badly decayed condition. Those slightly decayed, however, escape detection and, therefore, may be used for seed. The causal fungus may also enter through wounds, or invade surface lesions made by other fungi.

DISTRIBUTION

In 1913 (*17*) footrot was known to occur only in Virginia. By 1916 Iowa, Ohio, Missouri, and Kansas (*19*) were added to the list. In 1917 it was found in New Jersey, Maryland, and California. In New Jersey it is doing very little damage as yet, but in California and Maryland considerable loss resulted from it in 1917 and 1918, respectively. Just how long it has been present in California has not been learned. The organism isolated from material collected in California, when inoculated into healthy plants on the Potomac Flats, produced typical symptoms of the disease. In fact, it was found to be identical morphologically and parasitically with the strains isolated from material collected in Eastern States. The following varieties of sweet potatoes have been inoculated with *Plenodomus destruens* and the disease produced: Yellow Jersey, Big Stem Jersey, Pierson, Miles Yam, Early Carolina, Yellow Strasburg, Red Jersey, Red Bermuda, Extra Red Carolina, Southern Queen, Yellow Yam, Pumpkin Yam, Vineless Yam, Dooley, Triumph, Vineless Pumpkin Yam, Nancy Hall, Florida, General Grant Vineless Yam, White Yam, Red Brazilian, and Dahomey.

The footrot fungus produces a relatively slow decay, two to three weeks being required to destroy completely an average-sized potato. It produces a somewhat spongy rot and turns the tissue brown. Upon the escape of moisture it becomes dry, shrunken, hard, and finally brittle.

CHARCOAL-ROT

Charcoal-rot is a rather common type of storage-rot caused by *Sclerotium bataticola* Taub., and is distributed throughout the United States and elsewhere. It has been collected widely, and specimens of sweet potatoes have been received from Japan and other foreign countries decayed by *S. bataticola*. The writers have often isolated it from the lower part of the stem and underground parts of sweet-potato plants injured in the field by other agencies. It will grow saprophytically on most any substance, and occurs as a secondary invader both under field conditions and in the stroage house.

Sclerotium bataticola evidently was originally thought by Halsted (*12*) to be a stage in the life history of *Sphaeronema fimbriatum*, but after a more thorough study of the disease by Halsted and Fairchild (*15*) it was evident they entertained some doubt of its connection with the black-rot fungus. Later investigations (*34*), however, showed that the sclerotial form was *Sclerotium bataticola*, and was in no way connected with *Sphaeronema fimbriatum*.

Sclerotium bataticola is another of the slow-growing storage-rot fungi, requiring about 3 to 6 weeks to rot completely a potato under moist-chamber conditions at laboratory temperature. The decayed tissue first becomes a chocolate to a cinnamon-brown, followed by a dark reddish-brown color. As soon as the sclerotia begin forming, it becomes black or charcoal in appearance. Three distinct zones differing in color, therefore, may be distinguished in a potato at the same time. The black zone contains the sclerotial bodies. Adjacent to this is a dark reddish-brown area. The freshly decayed part is of a chocolate-brown color.

The potato in the early stages of decay is spongy, but on the escape of moisture it gradually becomes hard and mummified. In this stage the epidermis is darkened from the action of the fungus, but there is no other external indication that the potato is rotted. If the epidermis is broken, the black sclerotial bodies may be seen in large numbers. In a completely decayed potato these sclerotial bodies are buried among the cells throughout the potato.

INOCULATION EXPERIMENTS

Several inoculation experiments were carried out at different times, and in most cases when the well method described earlier was employed positive results were obtained. The writers found that *Sclerotium bataticola*, like some other storage-rot organisms, would not consistently

decay the potatoes when the hyphæ were inserted into wounds. Inoculated potatoes held at laboratory temperature and confined in a moist chamber would usually decay in from 3 to 6 weeks. A number of potatoes were inoculated on December 5, 1916, and 43 per cent were completely or nearly decayed by January 2, 1917. The causal organism was recovered from a potato rotted in the above experiment and used to inoculate another lot on January 22, 1917. Seventy per cent of the latter were from two-thirds to completely decayed by February 23.

SCURF

Scurf is a common field disease of sweet potatoes caused by *Monilochaetes infuscans* Hals. It is very prevalent in California, the entire South, and other sweet-potato growing sections of the country. Scurfy potatoes sell for from 25 to 50 per cent less on the market than clean ones, depending naturally on the severity of the infection. To this loss must be added those scurfy potatoes which are so badly dried and shrunken that they are not fit for food. The spotted discoloration of the skin is well known to nearly everyone (Pl. 26, B). These spots may be small and separate or they may coalesce so as to form a continuous discolored covering over the end or even over the entire potato. The discolored or infected areas are for the most part present in the field before the crop is harvested, though they may enlarge slightly in storage, and possibly a few new ones may be formed.

Although *Monilochaetes infuscans* is superficial, the hyphæ penetrating only through the cuticle (*19*), it injures the epidermis so that water escapes, thus resulting in a shrinkage of the potato. This shrinkage is slow, but after one or two months in storage a considerable percentage is unfit for the market. Naturally the shrinkage is greatest in houses where the relative humidity is low and the temperature is high. Plate 26, C, shows a badly shrunken scurfy potato. The shrinkage is generally worse at one end, usually the end that was attached to the stem. That there is more shrinkage at the attached end is not surprising when one remembers that scurf, like several other diseases of the sweet potato, is largely carried to the field on the slips. Being a surface organism, it readily grows from the slip on to the roots or is washed there by rains. That many of the infections on the attached ends results from the spores being washed down the stem on to the roots is evident from the fact that the infections for the most part are in spots.

There are no varieties of sweet potatoes immune to scurf, so far as the writers know. Data collected over a period of six years show that the following varieties of sweet potatoes are susceptible to scurf: Yellow Jersey, Red Bermuda, Japan Brown, Red Brazilian, Florida, White Gilke hybrid, Vineless Pumpkin Yam, Pumpkin Yam, Eclipse Sugar Yam, Porto Rico, Triumph, Yellow Yam, Yellow Strasburg, Early Carolina, Creola, Georgia, Miles Yam, Pierson, White Yam, Key West

Yam, Big Stem Jersey, Nancy Hall, Southern Queen, Dahomey, and several varieties with accession numbers but not yet named. McClintock (*26*) listed approximately these same varieties, stating that a number of them had little or no scurf when grown for a season in Virginia. The writers have found, however, that many of the varieties he listed as having little or no scurf were the most susceptible and worst affected in other sections of the country. There is, in the opinion of the writers, little difference in the susceptibility of the different varieties, since varieties which have shown a degree of resistance in one section of the country are not resistant in another.

MINOR STORAGE-ROTS

The following group of storage-rots are of minor importance. They are caused by fungi occasionally met with and which under the proper environment will decay sweet potatoes. That they have not been more frequently met may in part be due to the fact that they are slow-growing forms, and as such may be crowded out or overrun by the more rapidly growing saprophytes which follow them. This does not necessarily presuppose the killing out of the casual fungus, although such might well happen. It is a well-known fact that certain organisms do not live long in their own staling products. *Rhizopus nigricans*, for instance, will often die in two or three weeks in tissue previously destroyed by it. Other organisms, saprophytes perhaps, may find abundant food there and conditions otherwise congenial for their development. With these facts in mind it is easy to understand why a saprophyte instead of the causal fungus may be, and doubtless often is, isolated from decayed tissue. Furthermore, the causal fungus and a saprophyte may both be living congenially in the same decayed tissue, but when isolations are made the latter, if the more rapid grower, which it usually is, will so completely crowd out the parasite that only the saprophyte appears in the plate. Likewise the temperatures at which sweet potatoes are usually stored are the temperatures at which many of these minor rot-producing organisms do not grow well. It is at the low or high temperature, thus excluding some of the saprophytes, that some of these fungi grow. These fungi therefore have been found to cause rots and have been isolated from decayed potatoes held at a temperature lower than that at which sweet potatoes are usually stored.

With one or two exceptions none of the organisms have ever been reported to have produced decay of sweet potatoes in storage. No common names are known for these rots; therefore they will be discussed under the name of the causal organism.

MUCOR RACEMOSUS

In the course of the sweet-potato storage investigations potatoes have been exposed for varying lengths of time to temperature a little above freezing. After a few weeks at a temperature of 2.0° to 4.5° C. they were usually decayed, and in these rotted potatoes two or three fungi always predominated. One of the most common forms was *Mucor racemosus* Fes. In one experiment four sacks of about ¼ bushel each were stored for two months at 2.0° C., and all the potatoes were decayed with *M. racemosus*. A large number of potatoes have been inoculated at different times with pure cultures of *M. racemosus* and stored in the usual way in a sweet-potato storage house, but no infections resulted. However, in other experiments in which the potatoes were inoculated and then stored at a temperature of about 2° C. rot was produced and *M. racemosus* was isolated in pure culture after two or three months. In one such experiment 100 potatoes were inoculated and *M. racemosus* was recovered in pure culture from 82 per cent. The remaining 18 per cent were infected with an undetermined species of Mucor and five unknown fungi. That low temperatures are necessary was further proved by a number of experiments in which the potatoes were inoculated with pure cultures of *M. racemosus*, using the "well" method previously described, and confined in moist chambers. No decay resulted when these potatoes were exposed to the temperatures of the laboratory room or of an ice box (10°–14° C.). If, on the other hand, they were exposed to low temperatures, they were rotted readily, as shown by the following experiments.

In all these experiments the fungus was grown for 24 hours in sweet-potato decoction, and both the growth and the decoction poured into a "well," after which they were wrapped in filter paper and then in oiled paper. This served both to retain moisture and to prevent contamination. Before they were inoculated the potatoes were thoroughly washed and then disinfected with mercuric chlorid. After inoculation the potatoes were divided into several lots and placed in different chambers of the Altmann thermostat. In these and subsequent experiments only the average temperature covering the period of the experiment in the Altmann thermostat is given. The maximum and minimum varied 1 to 2 degrees above and below the average given. In one experiment only two chambers were used—viz, chamber 1 (average temperature 0.43° C.) and chamber 3 (7.2° C.). In three weeks 100 per cent of the potatoes in both chambers were from half to completely decayed. The experiment was repeated, using chambers 1 (0.67° C.), 2 (4.37° C.), 4 (8.1° C.), 5 (11.6° C.), 7 (14.7° C.), 10 (22.8° C.). In chambers 1, 2, and 4 all the potatoes rotted. The above experiment, in which 10 potatoes after inoculation were placed in chambers 2 (5.34° C.), 3 (7.81° C.), 4 (8.7° C.), 5 (11.0° C.), 7 (15.8° C.), 9 (17.5° C.), laboratory room

(23° C.), and an incubator the temperature of which averaged about 28° C., was twice repeated. In chambers 2 and 3, 70 per cent in the one series and 90 per cent in the other were decayed. The sweet potatoes at all other temperatures remained sound.

The results seem to indicate that *Mucor racemosus* produces a much slower rot than *Rhizopus nigricans*, about two to three weeks being required to complete the destruction of a sweet potato under optimum conditions. The tissue is rendered a clayish white in spots, as shown in cross section (Pl. 27, A). It is somewhat wet, but spongy to firm. When pulled apart or broken open, it pulls out in a fibrous, stringy manner. It has a distinct starchy odor.

ALTERNARIA SP.

Alternaria sp. is another fungus we have frequently isolated from sweet potatoes held at low temperatures. Owing to its prevalence under such conditions, inoculations were made by inserting spores and hyphæ into the end of some potatoes and exposing them to the temperature of chambers 3 (7.19° C.), 6 (14.4° C.), 9 (20.9° C.), 11 (26.0° C.), 16 (30.6° C.) of the Altmann thermostat. Each sweet potato was wrapped in filter paper and then in oiled paper. All the potatoes in chamber 3 were partially rotted in 19 days. In chamber 6 only a slight rot had started and at the higher temperatures all the potatoes remained sound to the close of the experiment.

Alternaria sp. produces a firm, moist rot. The tissue is first turned brown and then gradually darkens, but never becomes black (Pl. 27, B). The potato breaks easily, and the parts separate without the formation of strands so characteristic of soft rot.

PENICILLIUM SP.

The species of Penicillium which we most frequently isolated and with which all our work has been done was given to Dr. Charles Thom, of the Bureau of Chemistry, for identification. According to his determination it belongs to the *expansum* group, and is similar to a number of other strains for which there are no specific differences. It was a common inhabitant of decayed sweet potatoes and generally of those that were decayed by other fungi. Occasionally it was isolated alone in pure culture, but more often it was accompanied with one or more other organisms. Like some of the other fungi already discussed, it was most often obtained from potatoes held at low temperatures. That it may be, under a protected environment, a storage-rot producing organism at low temperatures was demonstrated by a series of experiments in which chambers 2 (4.44° C.), 5 (12.0° C.), 8 (18.7° C.), 10 (22.9° C.), 12 (26.9° C.), and 17 (32.0° C.) of the Altmann thermostat were used. In chambers 2 and 5 the potatoes were from one-fourth to two-thirds decayed in 39 days.. In

the other chambers all the potatoes remained sound. While the results show some success at low temperatures from inoculating sweet potatoes with *Penicillium* sp., this fungus, even when removed from the competition of other organisms, must for the most part be considered a saprophyte.

Penicillium sp. forms blue masses of spores on the interior and on the surface of the sweet potato (Pl. 27, C).

BOTRYTIS CINEREA

Botrytis cinerea Pers. was often isolated from sweet potatoes, as well as dasheens and other vegetables held at low temperatures. So commonly was *B. cinerea* isolated that the writers suspected it to be parasitic under the same conditions that several of the other fungi already discussed were found to be storage-rot producers.

Preliminary experiments were made first with raw sweet-potato blocks. It is not believed that the results from the use of raw sweet-potato blocks give a final proof of the parasitism of any organism, but they do give some indications of what may be expected when the potato itself is inoculated and exposed to similar temperatures. The raw blocks were cut and dropped into test tubes containing sweet-potato decoction, made according to the method described on page 339. These blocks were then inoculated with pure cultures of *Botrytis cinerea* and the tubes divided into five lots. One lot was placed in each of chambers 1 (1.12° C.), 2 (4.6° C.), 3 (6.15° C.), and 5 (9.4° C.) of the Altmann thermostat. This experiment was conducted with *B. cinerea* from two distinct sources. One strain (No. 3900) was isolated from sweet potatoes exposed to a temperature of 5° C. for several weeks and the other (No. 3940) from cabbage held in cold storage (0°–1° C.) for several weeks. In 16 days after inoculation all the plugs were rotted in all the chambers by both strains. The fungus fruited in the tubes. Controls held for the same experiment remained sound to the close of the experiment.

The above results were verified by an experiment in which potatoes were used, nine of which after inoculation (strain 3940) by the "well" method were put in each of compartments 1 (2.4° C.), 2 (3.56° C.), 4 (7.5° C.), 6 (13.9° C.), 9 (20.9° C.), and laboratory room. The results showed that this organism would decay sweet potatoes over a considerably wider range of temperatures than was the case with some of the other organisms which are virulent only at low temperatures. In fact, the rot did not progress as rapidly in the low temperatures as in temperatures a little higher. In other words, it required 30 days to completely decay the potatoes in chambers 1 and 2, while in chambers 4 and 6 the potatoes were entirely rotted in 20 days. In chamber 9 only two were completely rotted, and the remainder partially so in 23 days. In the laboratory room one potato was completely rotted and six partially so in 23 days;

the other remained sound. From this experiment it seems that medium temperatures are more favorable to *Botrytis cinerea* than the higher or lower ones.

Botrytis cinerea produces a grayish, soft, somewhat watery rot (Pl. 27, D). The tissue of the sweet potato pulls out in strings when broken apart. It has a somewhat starchy odor.

EPICOCCUM SP.

Although this fungus can not be regarded as of much economic importance, it was so often isolated from rotted sweet potatoes held at low temperatures that it can not be passed over without mention. It grows rather slowly and is probably able to cause decay only at such temperatures at which the competition of other fungi is reduced.

From a lot of sweet potatoes which had been thoroughly washed and then stored at 0°, 5°, and 10° C. *Epicoccum* sp. was about the only fungus isolated. Later a series of experiments were conducted in which sound potatoes were inoculated with pure cultures by the "well" method and exposed to the temperatures of chambers 3 (7.19° C.), 6 (14.4° C.), 9 (20.9° C.), and 11 (26° C.) of the Altmann thermostat. All the potatoes in chamber 3 were slightly to completely decayed in three weeks. In the other compartments they remained sound.

Epicoccum sp. produces a slow, firm rot. The tissue is rendered at first slightly yellowish followed by a reddish brown color (Pl. 27, E).

GIBBERELLA SAUBINETII

From the number of species of Fusarium that can be isolated from decayed sweet potatoes only a few have been shown to cause storage rots. Because of the almost omnipresence of some of the species of Fusarium an immense amount of work was done with these fungi. Strange to say, those species most frequently isolated are those which the writers were unable to prove parasitic or rot-producing organisms. On the other hand, those species shown to be capable of causing decay are, comparatively speaking, seldom found under natural conditions.

EXPERIMENT I.—Experimental work with this organism as a storage-rot fungus was started in 1914, when 75 potatoes after a thorough washing were divided into two lots, one of which was disinfected in formalin (1:200) for 30 minutes. Both lots were inoculated with *Gibberella saubinetii* (Mont.) Sacc. from pure culture by inserting spores and hyphæ into wounds. The treated lots only were wrapped in oiled paper. The two lots were then placed in storage, the temperature of which was maintained at about 2.0° C. They were left in storage for four months, when they were removed and isolations made from each potato. *G. saubinetii* was recovered in pure culture from only 20 per cent of the untreated and from 34 per cent of the treated lot. From the other

potatoes a miscellaneous lot of fungi was isolated, *Mucor racemosus* and *Mucor* sp. predominating. The sweet potatoes were a long time in storage at such a temperature, and, if not supported by other experimental data, these results would have little value. Even then they would hardly deserve to be included did it not form a link in the chain of experiments conducted with this organism and several species of Fusarium. All the controls in the above experiment were rotted, but none with *G. saubinetii*.

EXPERIMENT II.—On October 29, 1914, 40 sweet potatoes, after a thorough washing, were divided into two equal lots. One lot was disinfected for 30 minutes in a 1 to 200 solution of formaldehyde (40 per cent). The two lots were inoculated by inserting spores and hyphæ into a wound. The potatoes were then immediately immersed in a suspension of the spores in sterile water, after which they were wrapped in moistened filtered paper and then in oiled paper and placed in cloth bags. The two lots were stored near together in a sweet-potato storage house at Arlington Experimental Farm, Virginia. These potatoes were removed from storage March 11, 1915, and cultures made from those that were partially or completely decayed. Sixty-seven per cent of the treated lot remained sound; the others were from one-third to two-thirds decayed. *Gibberella saubinetii* was isolated in pure culture from 85 per cent of those that were decayed. Fifty per cent of the untreated lot (10 potatoes) remained sound and *G. saubinetii* was isolated from 90 per cent of those that were decayed. Thirty-five per cent of the controls (20 sweet potatoes) rotted slightly, but *G. saubinetii* was not isolated from any of these.

EXPERIMENT III.—A third lot (21 sweet potatoes), disinfected as above and wrapped but not immersed in a spore suspension, was stored in an Irish potato storage house. The temperature here was naturally lower than that of a sweet potato storage house, probably about 2.0° to 4.5° C. All these potatoes were more or less decayed and *Gibberella saubinetii* was recovered in pure culture from 67 per cent. The controls were also decayed, but *G. saubinetii* was not isolated from any.

EXPERIMENT IV.—In this experiment the sweet potatoes (40) were first placed in cold storage for one week and then inoculated by inserting spores and hyphæ into a wound, after which they were returned to cold storage. Before inoculation one lot was disinfected as above in formalin and wrapped. The potatoes were all decayed when removed from storage. *Gibberella saubinetii* was recovered from 90 per cent of the treated and 40 per cent of the untreated.

Gibberella saubinetii renders the sweet potatoes at first spongy in texture and brown in color. At a later stage, as moisture escapes, the tissue becomes firmer and finally hard and mummified. The brown color is later replaced by a pinkish-brown tint.

FUSARIUM CULMORUM

The experiments with *Fusarium culmorum* Wollenw. as well as *F. acuminatum*, to be discussed later, were for the most part carried out like those of *Gibberella saubinetii*.

EXPERIMENT I.—Eighty potatoes were thoroughly washed and divided into two lots. One lot was disinfected in formalin (1:200) for 30 minutes. After inoculation by inserting spores and hyphæ the treated lot was wrapped in oiled paper and stored at 2.0° C. When they were removed from storage, cultures were made from each potato. *F. culmorum* was isolated in pure culture from 95 per cent of the treated and 25 per cent of the untreated lot. The other potatoes were decayed, but a miscellaneous lot of fungi, of which *Mucor racemosus* and *Mucor* sp. predominated, was isolated. *F. culmorum* was not isolated from any of the controls. A more detailed discussion of the method may be found under experiment I of *Gibberella saubinetii*.

EXPERIMENT II.—The method of manipulation in this experiment is identical with that of Experiment II of *Gibberella saubinetii*. Two lots of potatoes (20 in each lot) were removed from the sweet-potato storage house on March 11 and cultures made from each decayed or partially decayed potato. Sixty per cent of the treated lot (formalin, 1:200, 30 minutes) were one-half to two-thirds decayed, and 80 per cent of the untreated were partially to completely so, and *F. culmorum* was isolated from all in pure culture. The other inoculated potatoes and the controls remained sound.

EXPERIMENT III.—For method see Experiment III of *Gibberella saubinetii*. This experiment differs from Experiment III above in that there were two lots, only one of which was treated. All these potatoes were decayed when removed from storage, and *F. culmorum* was isolated from 100 per cent of the treated potatoes and 95 per cent of those not treated. While most of the controls were decayed, *F. culmorum* was not isolated from any.

EXPERIMENT IV.—For method see Experiment IV of *Gibberella saubinetii*. These sweet potatoes were kept in storage from September 9 to January 18, when they were removed and cultures made from those partially or completely decayed. Ninety-five per cent of the treated and 80 per cent of the untreated potatoes were rotted with *F. culmorum* and the causal organism recovered in pure culture from each.

EXPERIMENT V.—Chambers 4 (10.6° C.), 5 (13.5° C.), 7 (16.9° C.), 9 (20.5° C.), 10 (21.2° C.) of the Altmann thermostat and laboratory room (23° C.) were used for this experiment. The potatoes were thoroughly washed, then disinfected in mercuric chlorid (1: 1,000) for 10 minutes. They were inoculated on November 6 by inserting spores and hyphæ into a wound at the end, after which they were wrapped in moistened filter paper and then in oiled paper. On January 3 they were removed from

the different chambers and cultures made. All the potatoes in chamber 4 (10.6° C.) were decayed, and *F. culmorum* was recovered in pure culture. Only 10 per cent were decayed in chambers 5 (13.5° C.) and 7 (16.9° C.), and *F. culmorum* was isolated from all. The potatoes in the other chambers and all the controls remained sound.

F. culmorum produces a distinctively characteristic rot and when once seen would never be confused with any of the other rots except that caused by *F. acuminatum*, from which it does not differ macroscopically. The organism decays the sweet potato slowly, requiring three to six weeks to complete its entire destruction. The tissue is rendered spongy but not watery. In the early stages the tissue of the host is a faint reddish brown, which turns later to a carmine-red or maroon. As the potato dries out, some of the deep color is lost, and in the mummified stage it becomes a beautiful pink.

FUSARIUM ACUMINATUM

EXPERIMENT I.—The method is identical with that used in Experiment I of *F. culmorum*. When these sweet potatoes were removed from storage, all of the treated potatoes and 75 per cent of those not treated were decayed, and *F. acuminatum* Ell. and Ev. emend. Wollenw. was recovered from each in pure culture. The only other fungi isolated were *Mucor racemosus* and *Mucor* sp.

EXPERIMENT II.—The method is the same as in Experiment II of *Gibberella saubinetii*. When these sweet potatoes were removed from storage, only a small percentage had decayed. *F. acuminatum* was recovered from 5 per cent of the treated lot and 17 per cent of those not treated. *F. oxysporum* was recovered from a few other potatoes.

EXPERIMENT III.—The same method was used as that in Experiment III of *Gibberella saubinetii*. When these sweet potatoes were removed from storage, *F. acuminatum* was isolated from 75 per cent of the treated and 90 per cent of the untreated. The only other fungi isolated were *Mucor racemosus* and a species of Penicillium.

EXPERIMENT IV.—The method was the same as that used in Experiment IV of *Gibberella saubinetii*. All the sweet potatoes were decayed, and *F. acuminatum* was isolated in pure culture from 95 per cent of both the treated and untreated. Controls were held for all these experiments and while, as might be expected, some of them were decayed, for which several fungi were responsible, *F. acuminatum* was not isolated from any.

TRICHODERMA KONINGI

We owe our first knowledge of a storage-rot of sweet potatoes caused by *Trichoderma koningi* Oud. to Cook and Taubenhaus (*8*), who found it associated with ringrot and softrot. It probably falls into the class with several other organisms of minor importance which can cause decay

of the roots when removed from the competition of other fungi. The writers have seldom isolated the fungus, and in no case has it ever been obtained from wounds or decayed tissue where it seemed the primary cause of the rot. Cook and Taubenhaus were able to infect sweet potatoes artificially by inoculating them with pure cultures of *T. koningi*. A rot differing somewhat from that caused by *T. koningi* in character was produced by artificial inoculation with *T. lignorum* (Lode.) Harz. The latter fungus, however, was not isolated from sweet potatoes, but was obtained by the investigators mentioned above from Dr. Thaxter. Both of these species of Trichoderma are widely distributed fungi, and *T. koningi* is especially common in the soil. Therefore it is not surprising to find it associated with other fungi in the rotted tissue of sweet potatoes.

The symptoms caused by *T. koningi* are described by Taubenhaus and Manns (*37, p. 24*) as follows:

> In the earliest stages the spots are circular and of a light brown color, with a tendency to wrinkle. The flesh is hard and watersoaked, brown in color, with a black zone in the region between the healthy and diseased tissue. The spot enlarges in all directions and eventually destroys the entire root.

DISCUSSION OF RESULTS

In the foregoing pages 17 organisms have been found to bear some relation to storage-rots of sweet potatoes. Naturally, some of these are of minor importance, but perhaps largely because the conditions suitable to their needs are not usually maintained in the storage house. In fact, there is not a single organism here discussed which did not exhibit a preference for certain evironmental conditions. Such fungi as *Rhizopus nigricans* and *Sphaeronema fimbriatum* find conditions suitable for them to rot sweet potatoes at the usual storage temperature (50° F.) or at higher temperatures. On the other hand, such organisms as *Mucor racemosus*, *Botrytis cinerea*, and others find such temmperatures unsuited to their needs and bring about destruction of the host only at temperatures considerably lower than that usually recommended for the storage of the crop.

Humidity was shown to play an important part. *Rhizopus nigricans* requires a relatively high humidity until it has once started, after which it will complete the destruction of the potato in an atmosphere almost entirely free of moisture. *Sphaeronema fimbriatum* also grows better in the presence of abundant moisture. *Diplodia tubericola*, on the other hand, will grow in a relatively dry atmosphere from the outset. *R. nigricans* completes the destruction of the potato in a few days, while *D. tubericola*, *Diaporthe batatatis*, and others are slow growers, requiring from three to eight weeks.

Although the writers have discussed at some length organisms which thrive best at temperatures below that recommended for the storage of the crop, sight must not be lost of the fact that the recommendations for

storage are not universally followed and not necessarily trusted by everyone. We have occasionally found sweet potatoes stored with Irish potatoes and in cellars with cabbage, turnips, and other root crops for which a low temperature was required. In the South most of the sweet potatoes are stored in earth banks, and often when these are opened a considerable percentage of all of the crop is found decayed. The potatoes about the edges and on top in some of these banks are frozen, indicating that probably the entire lot had been exposed to a low temperature perhaps for a considerable length of time. Furthermore, sweet potatoes are taken from storage during the winter and shipped distances requiring from 3 to 12 days or more for them to reach the market. Since most of these shipments are to the northern and eastern markets, they may be, and frequently are, subjected to a low, if not freezing, temperature. After reaching the terminals they may be subjected to lower temperatures for a considerably longer period by the usual methods of handling. An examination of such material showed that they often arrive in bad condition. Many of the potatoes are rotted or partially so and unsalable. A study of such material, as well as material taken from cellars and Irish potato storage houses, shows that they are not decayed by *Rhizopus nigricans* and some of the other well-known storage-rot fungi, but by some of the forms discussed above, requiring low temperatures, as, for example, *Mucor racemosus* or *Botrytis cinerea*. So, bearing in mind the fact that sweet potatoes, even in storage, during transportation, and at the terminals may be subjected to the temperatures suited to some of these forms, it will be readily understood that the loss caused by these organisms may be considerable. Moisture is, of course, essential for those forms which are so much in evidence at low temperatures. In the banks there is little, if any, provision made for the escape of moisture. In cellars and in storage houses designed primarily for other purposes it is inadequately provided for. Sweet potatoes are generally shipped in barrels or bushel baskets and the moisture may accumulate in car-load shipments, especially if the temperature is low. The optimum comditions for some of these fungi are, therefore, unavoidably provided.

The facts presented as to the specific requirements of various fungi in general are not new. Link (*25*) has shown that while both *Fusarium oxysporum* and *F. trichothecioides* Wollenw. can produce tuber-rots and wilt of the Irish potato, the optimum temperature of *F. oxysporum* is higher than that of *F. trichothecioides*. Similar data has been published by Brooks and Cooley (*4*), who found from a study of the temperature relations of the apple storage-rots that the optimum temperature requirements of the various fungi differed greatly. *Sphaeropsis malorum* produced no evident rot at 15°, nor did the species of Penicillium and Neofabraea at 10° at the end of a week, while *Sclerotinia cinerea* produced a measureable rot at 5° in one week and at 0° in two weeks. The optimum temperature of *Neofabraea malicorticis* was found to be 20°, *F. radicicola* 30°, all the

other fungi 25°. The range of optimum temperature requirements for apple-rot fungi is even greater than for the storage-rot fungi of the sweet potato. That cool weather is required for infection of the Irish potato by the lateblight fungus, *Phytophthora infestans*, is well known. On the other hand, Gilman (*11*) concludes that relative high temperatures are required for infection of cabbage by *F. conglutinans* and Tisdale (*38*) arrives at similar conclusions for the infection of flax by *F. lini*. Other references might be made to show that the various fungi have different temperature requirements. On this point no generalizations can be made.

OTHER FUNGI ISOLATED AND STUDIED

A considerable number of other fungi, mostly species of Fusarium has been isolated and studied—namely, *F. batatatis* Wollenw., *F. hyperoxysporum* Wollenw., *F. radicicola* Wollenw., *F. caudatum* Wollenw., *F. solani* (Mart.) Sacc., *F. incarnatum* (Rob.) Sacc., *F. orthoceras* Appel and Wollenw., *F. orthoceras* var. *triseptatum* Wollenw., *F. oxysporum* Schlect., *Nectria ipomoeae* Hals., and an undetermined species of Mucor. These fungi have all been subjected to the same tests of parasitism as those classed as storage-rot organisms.

Preliminary experiments were conducted in which sweet potatoes were inoculated at the end or in some wound and then confined in a moist chamber, both wrapped and not wrapped in moist filter paper and then in oiled paper. They were inoculated by wounding and then dipped in spore suspensions and confined in moist chambers but without result. Chilling the potatoes by exposing them to cold-storage temperatures (2.0° C.) for a week and then inoculating in the usual way did not yield results. Soaking in water before inoculation was without effect. A large number of sweet potatoes have been inoculated, after which they were divided up into several lots and exposed to the temperatures of the different chambers of the Altmann thermostat. In no case were the results consistent enough to warrant the conclusion that any of these organisms would cause decay at the temperatures used.

Fusarium batatatis and *F. hyperoxysporum* are the two species well known as the cause of stemrot (*23*) of sweet potatoes. These two organisms frequently invade the fibrovascular bundles of the roots, often extending entirely through the potato. To know whether these organisms caused storage-rots is of considerable importance in view of their prevalence and destructiveness to certain varieties in some parts of the country. Roots naturally infected have been gathered and stored in bushel baskets in the storage houses with the other potatoes, and in every case they kept just as well as healthy potatoes. Naturally infected roots, after a thorough washing, have been wrapped in wet filter paper and then in oiled paper and subjected to the temperatures of the different chambers of the Altmann thermostat. Not in a single chamber did any of the potatoes rot. The writers conclude from these results that these

two organisms do not cause storage-rots. However, another organism, *F. oxysporum*, which might easily be mistaken for *F. batatatis* but hardly for *F. hyperoxysporum*, is one of the most common inhabitants of decayed sweet potatoes. In most storage houses it is common to find potatoes decayed at the end for a distance of ½ to 1½ inches, the tissue being brown and firm and emitting a pleasant aromatic odor (Pl. 27, F). From such decayed ends and from certain surface lesions and wounds *F. oxysporum* is the most common species of Fusarium isolated with any degree of regularity. Occasionally other fungi may be isolated, as, for example, *Plenodomus destruens*, *Nectria ipomoeae*, or *F. orthoceras*. Although it is the belief of the writers that *F. oxysporum* does cause an endrot of stored sweet potatoes we have consistently failed to obtain proof of it by any of the methods employed.

Nectria ipomoeae Hals. is another fungus frequently found on decayed sweet potatoes. It was first thought by Halsted to be the cause of the stemrot of sweet potato and eggplant, but was later shown (*22*) to be only a saprophyte. Since it was frequently isolated from rotted sweet potatoes, *N. ipomoeae* was suspected of causing a storage-rot, but like many of the other organisms studied, it consistently failed to give positive results by any of the methods tried.

Fusarium caudatum is not a common inhabitant of decayed sweet potatoes. It was originally isolated from a number of sweet potatoes sent from Clemson, S. C., by Prof. H. W. Barre. Prof. Barre said that several hundred bushels had been thrown out of a storage house similarly decayed. The decayed potatoes were brown in color, firm in texture, and had a very pleasing aromatic odor. We were unable by any of the methods tried to prove this organism the cause of a storage rot. None of the other forms with the exception of *F. radicicola* are very common. This species of Fusarium was frequently isolated from decayed potatoes and from the wounds and lesions of field material, especially from the South. However, in our experiments it has given no evidence of being a storage-rot producer. It is a common soil saprophyte and probably a secondary invader.

At different times other fungi have been isolated with which no experiments have been conducted. They were so rarely met with that inoculation experiments did not seem justified. Among others the following may be mentioned: *Zygorhynchus* sp., *Penicillium* sp., *Melanospora* sp., *Trichosporium* sp., *Ceratostoma* sp., *Sporotrichium* sp., *Pestalozzia* sp., *Aspergillus niger* Von Tiegh, *Sclerotium rolfsii* Sacc., *F. vasinfectum* Atk., *Cephalothecium* sp., *Neocosmospora vasinfectum* Atk.,, *Verticillium cinnabarinus*, *Acromoniella* sp., *Macrosporium* sp., *Actinomyces* sp., and others.

SUMMARY

(1) Storage-rots of sweet potatoes are estimated to cause a loss of many million dollars annually.

(2) Seventeen different fungi were found responsible for the decay of sweet potatoes in storage.

(3) A few of these fungi—viz, *Rhizopus nigricans*, *Sphaeronema fimbriatum*, *Diplodia tubericola*, *Diaporthe batatatis*, *Plenodomus destruens*, *Sclerotium bataticola*, and *Monilochaetes infuscans* are responsible for the most of the loss.

(4) The following fungi cause losses in storage under favorable conditions and are designated as the minor rot-producing fungi: *Mucor racemosus*, *Alternaria* sp., *Penicillium* sp., *Botrytis cinerea*, *Epicoccum* sp., *Gibberella saubinetii*, *Fusarium culmorum*, *F. acuminatum*, and *Trichoderma koningi*.

(5) Most of these fungi are weak wound parasites capable of causing decay of sweet potatoes only under particularly favorable conditions. *Rhizopus nigricans*, which probably causes more loss than any other organism, would not consistently infect sweet potatoes without first germinating the spores. When the germinated spores and decoction in which they were suspended were poured into a "well" in the potato, infection would usually follow.

(6) After infection had once started, *Rhizopus nigricans* would complete the destruction of a potato in an atmosphere almost entirely lacking moisture.

(7) There was great variation in the time required for the different fungi to completely decay a potato. For *Rhizopus nigricans* from three to five days were required. *Diplodia tubericola*, *Diaporthe batatatis*, and others required three to eight weeks under similar conditions.

(8) Most of the fungi required a considerable amount of moisture. In fact, wrapping in moistened filter paper was often necessary after inoculation by the "well" method. *Diplodia tubericola*, on the other hand, grows as well or better in a humidity of about that of the laboratory room.

(9) The optimum temperature of the different organisms varied considerably. The optimum for *Rhizopus nigricans* was comparatively high, but it would decay the potatoes over a considerable range of temperatures. On the other hand, *Mucor racemosus*, *Fusarium culmorum*, *F. acuminatum*, and others had a relatively low optimum.

(10) Some of these storage-rot fungi are also the cause of field diseases of sweet potatoes. Such are *Sphaeronema fimbriatum*, *Plenodomus destruens*, and *Monilochaetes infuscans*.

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PLATE 21

A.—Sweet-potato softrot, caused by *Rhizopus nigricans*. Only three to four days are required to rot completely the potato. If the atmosphere is sufficiently moist and the epidermis is broken, the sporangia develop superficially in great abundance.

B.—Sweet-potato ringrot, caused by *Rhizopus nigricans*. Ringrot differs from softrot only in that the decay extends around the potato at one or more places between the two ends. The causal organism may or may not advance toward the two ends, finally completing the destruction of the potato.


A
B
B


A
B

PLATE 22

A.—Blackrot of sweet-potato slips caused by *Sphaeronema fimbriatum*. Note the black cankers on the underground part of the stem. The causal fungus grew onto the slips from a blackrotted potato used for seed. The use of infested soil in the hotbed will cause similar infection.

B.—Blackrot on a bedded sweet potato. Note the young sprouts not yet through the ground being invaded by the fungus.

PLATE 23

A.—A sweet potato with four blackrot spots caused by *Sphaeronema fimbriatum* taken from a storage house in November.

B.—The same sweet potato shown in A after being kept in an ice box for two months. The temperature of the ice box was about the same as that recommended for the storage of sweet potatoes. Note that the spots have enlarged and united so as to involve nearly the entire potato.


A
B


A
B
C

PLATE 24

A.—An originally healthy sweet potato sprayed with the spores of *Sphaeronema fimbriatum* and confined in a moist chamber. The infections take place mostly through small rootlets or through wounds.

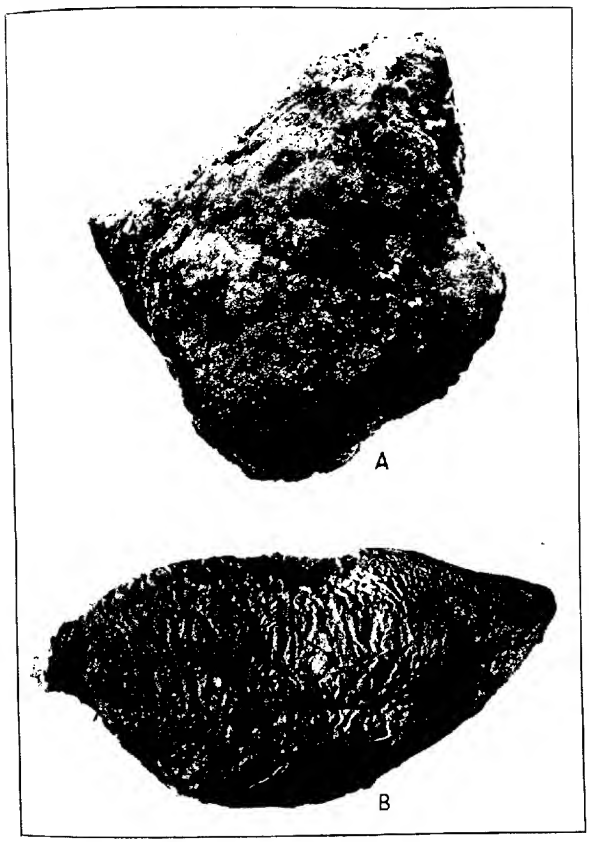
B.—A typical blackrot spot on a sweet potato as usually found at digging time or in storage.

C.—Cross sections of blackrot sweet potatoes, showing the depth to which the fungus will sometimes penetrate. Pure cultures of *Sphaeronema fimbriatum* were obtained from the deepest portion of the rot of these two sections.

PLATE 25

A.—A sweet potato decayed by the Java blackrot fungus, *Diplodia tubericola*. Numerous pycnidia may be seen on the surface.

B.—A sweet potato decayed by the dryrot fungus, *Diaporthe batatatis*. Note the dry, shruken appearance of the potato.


A
B

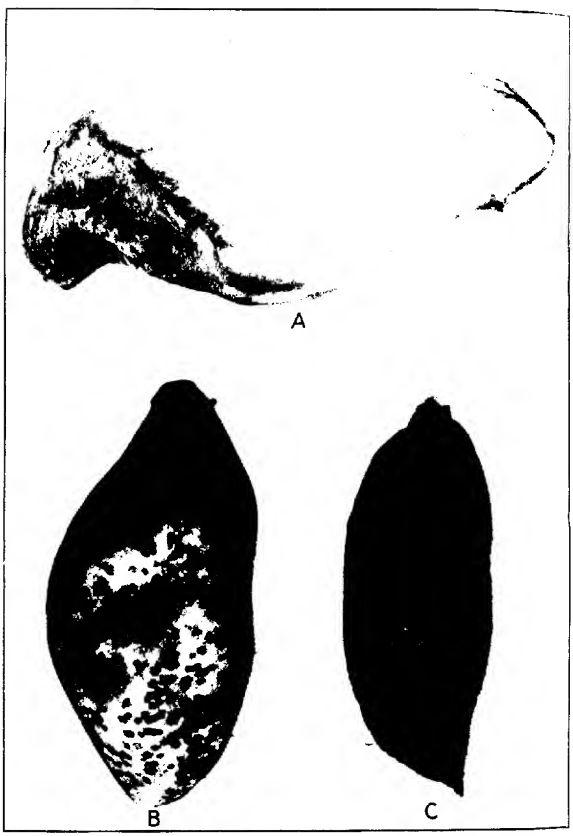

A
B
C

PLATE 26

A.—A section through a sweet potato partially decayed by the footrot fungus, *Plenodomus destruens*.

B.—Sweet-potato scurf, caused by *Monilochaetes infuscans*. The number of infections is shown by the black spots on the surface.

C.—A sweet potato entirely covered with scurf. In infections as bad as this the potato shrinks and finally dries up, becoming eventually worthless.

PLATE 27

A.—A cross section of a sweet potato decayed by *Mucor racemosus* at a temperature of 5° C. The mottled appearance is characteristic of rot caused by this fungus at low temperatures.

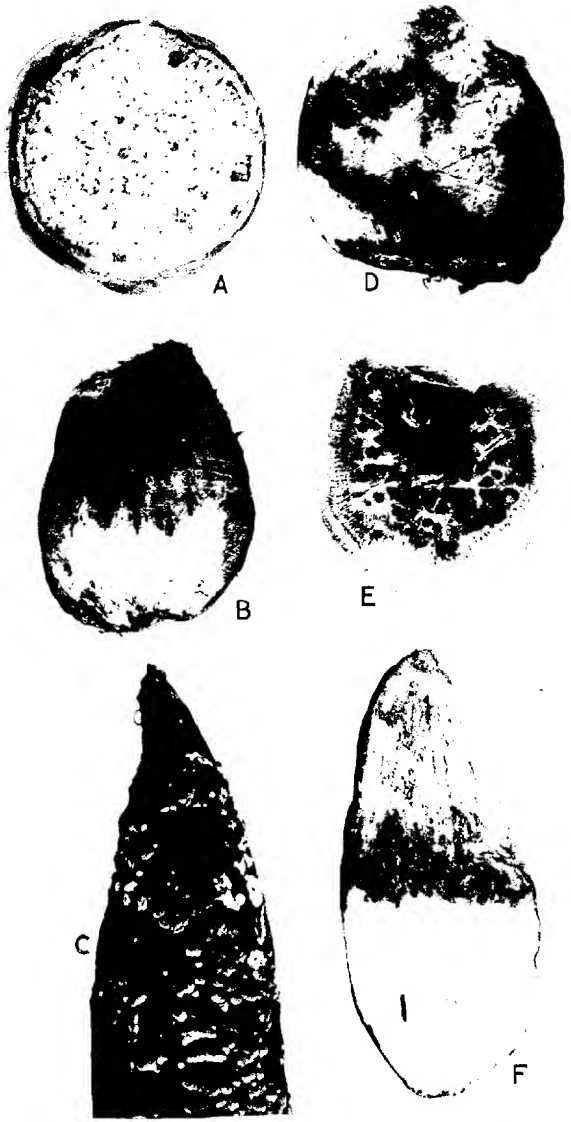
B.—A longitudinal section of a sweet potato decayed by *Alternaria* sp. The tissue becomes a very dark brown to nearly black.

C.—A portion of a sweet potato probably decayed by *Penicillium* sp. Note the numerous cushions of the fungus on the surface.

D.—A cross section of a sweet potato showing the characteristic appearance of the rot caused by *Botrytis cinerea*.

E.—A cross section of a sweet potato almost completely decayed by *Epicoccum* sp. The netted string-like appearance, also the yellowish color produced at some stages in the progress of the rot, is characteristic of the decay caused by this fungus.

F—A longitudinal section of a partially decayed sweet potato. This so-called end-rot is quite common in storage. *Fusarium oxysporum* is generally isolated from such decayed tissue. Although this fungus is believed to be the cause of endrot, inoculation experiments have never given consistent results.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